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# United States Patent [19]

Pearl et al.

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[54] MEMBRANE FILTRATION APPARATUS

2 013 522 8/1979 United Kingdom .

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[21] Appl. No.: 624,830

[22] Filed: Mar. 27, 1996

[51] Int. Cl.<sup>6</sup> ..... B01D 63/08

[52] U.S. Cl. .... 210/321.75; 210/321.84;  
210/450; 210/455

[58] Field of Search ..... 210/321.75, 321.84,  
210/450, 453, 455, 321.6, 321.64

[56] References Cited

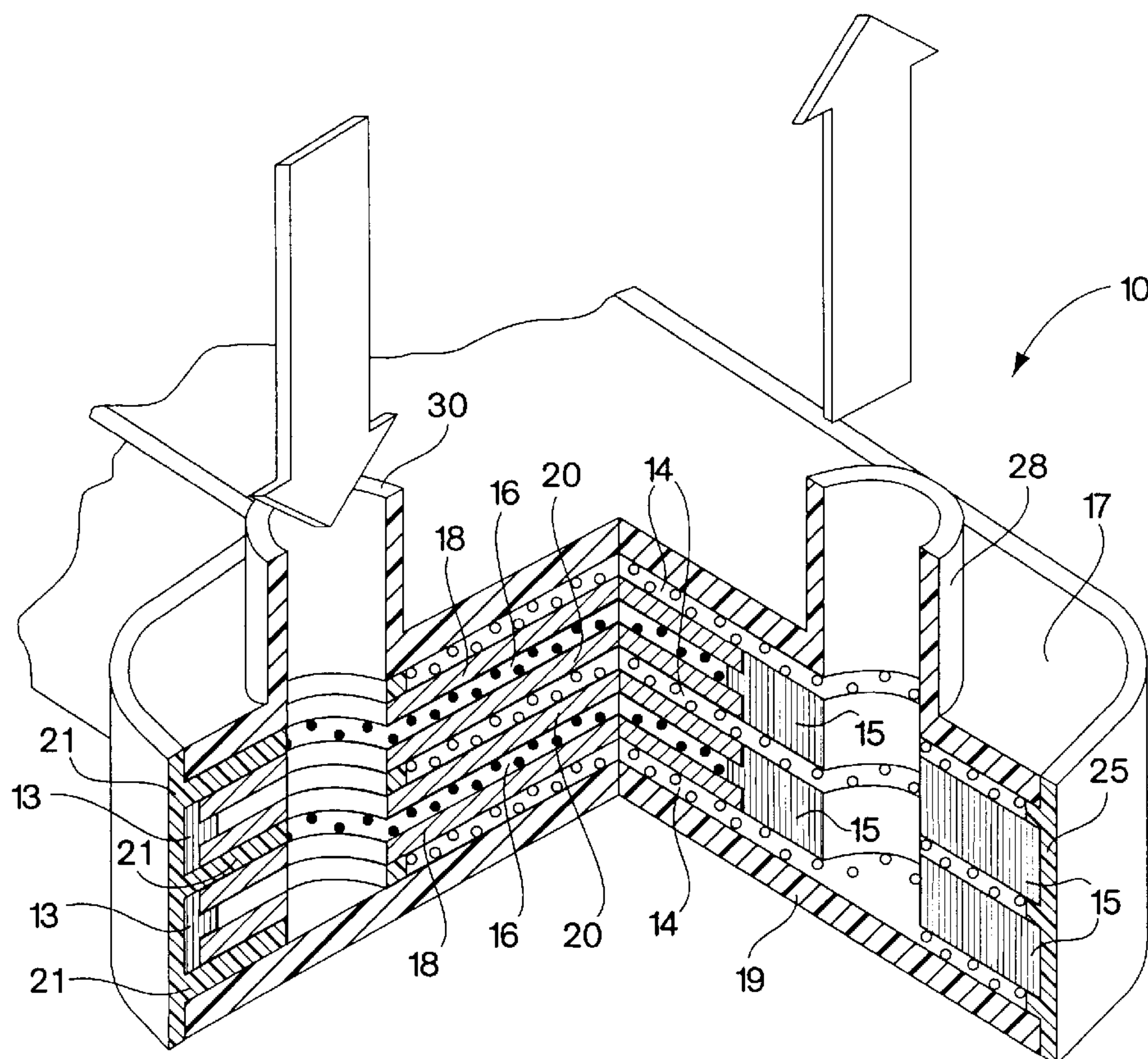
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[57] ABSTRACT

A filtration apparatus is provided which is formed from multilayer presealed elements and monolayer elements that are insert molded together. The device is provided with a feed port, a filtrate port and, optionally, a retentate port. The sealing configuration of the presealed elements and the seal provided by the insert molding step effect a seal configuration that causes a feed liquid to be filtered to form a filtrate such that the filtrate is not mixed with either the feed or a retentate.

26 Claims, 16 Drawing Sheets



MEMBRANES, 18,20



FEED SPACER, 16



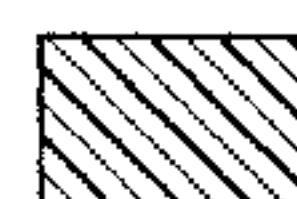
FILTRATE SPACER, 14



MODULE FIRST SEAL, 13,15



END CAPS, 17,19



SECOND SEAL, 21,25

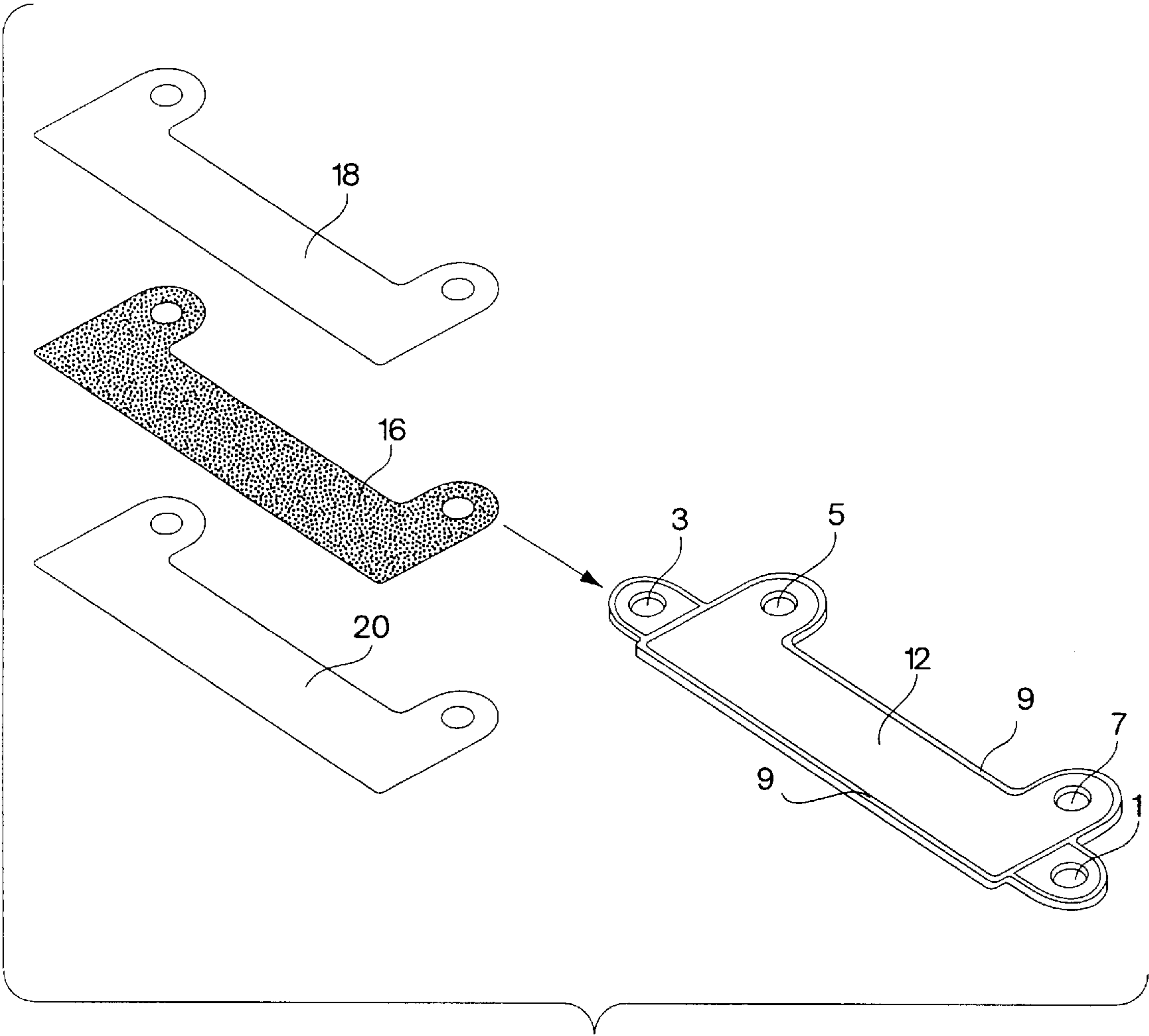


Fig. 1

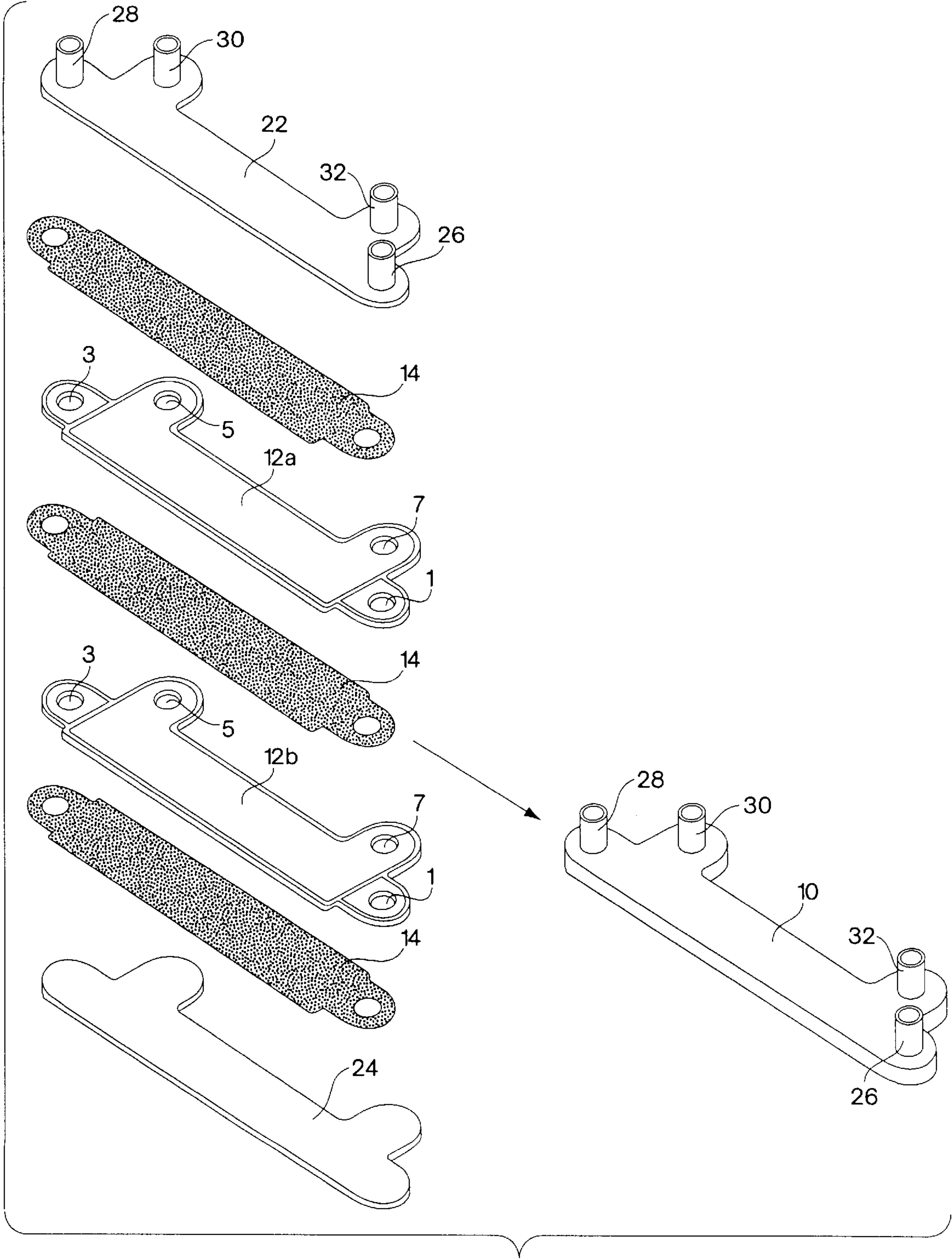
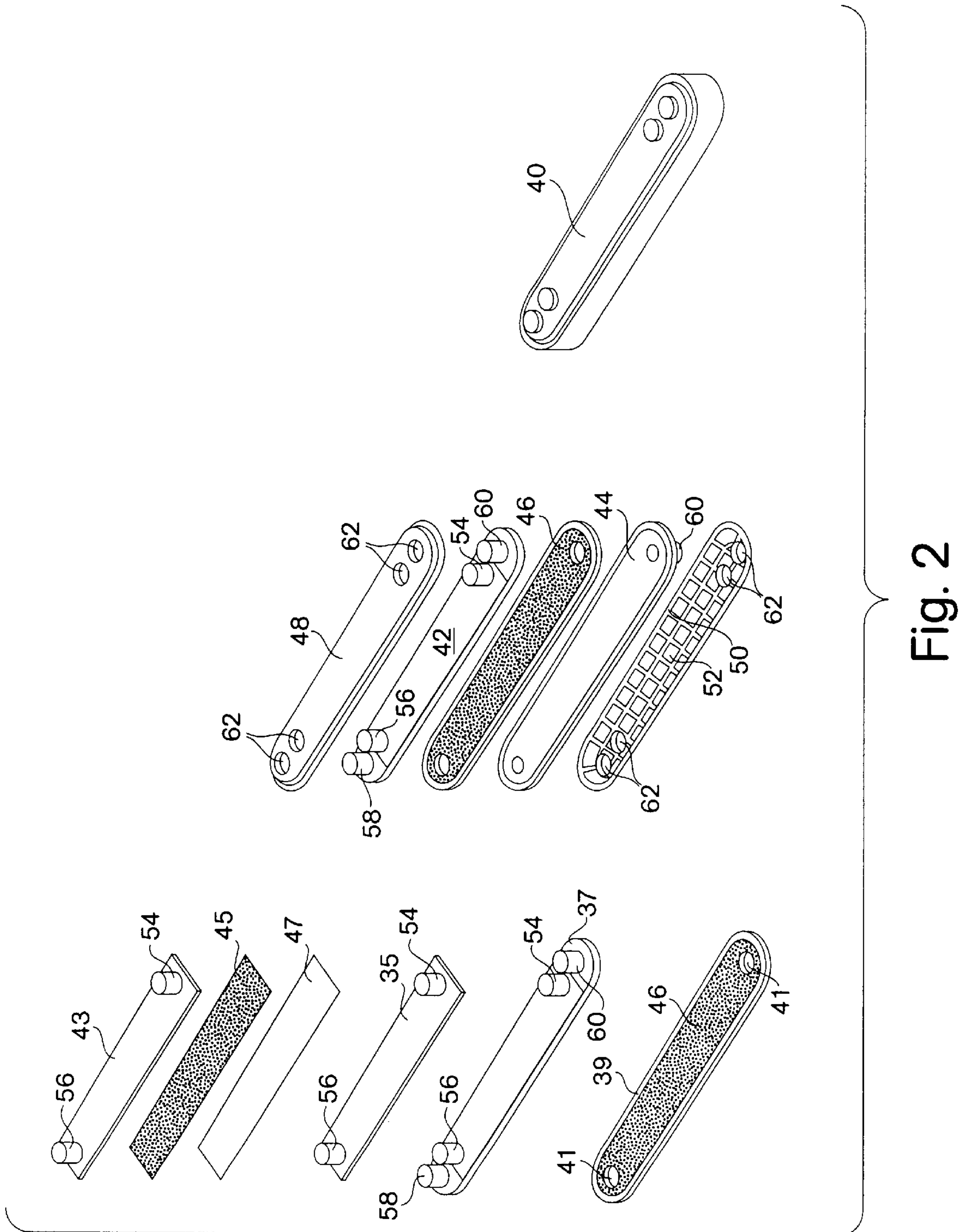


Fig. 1A





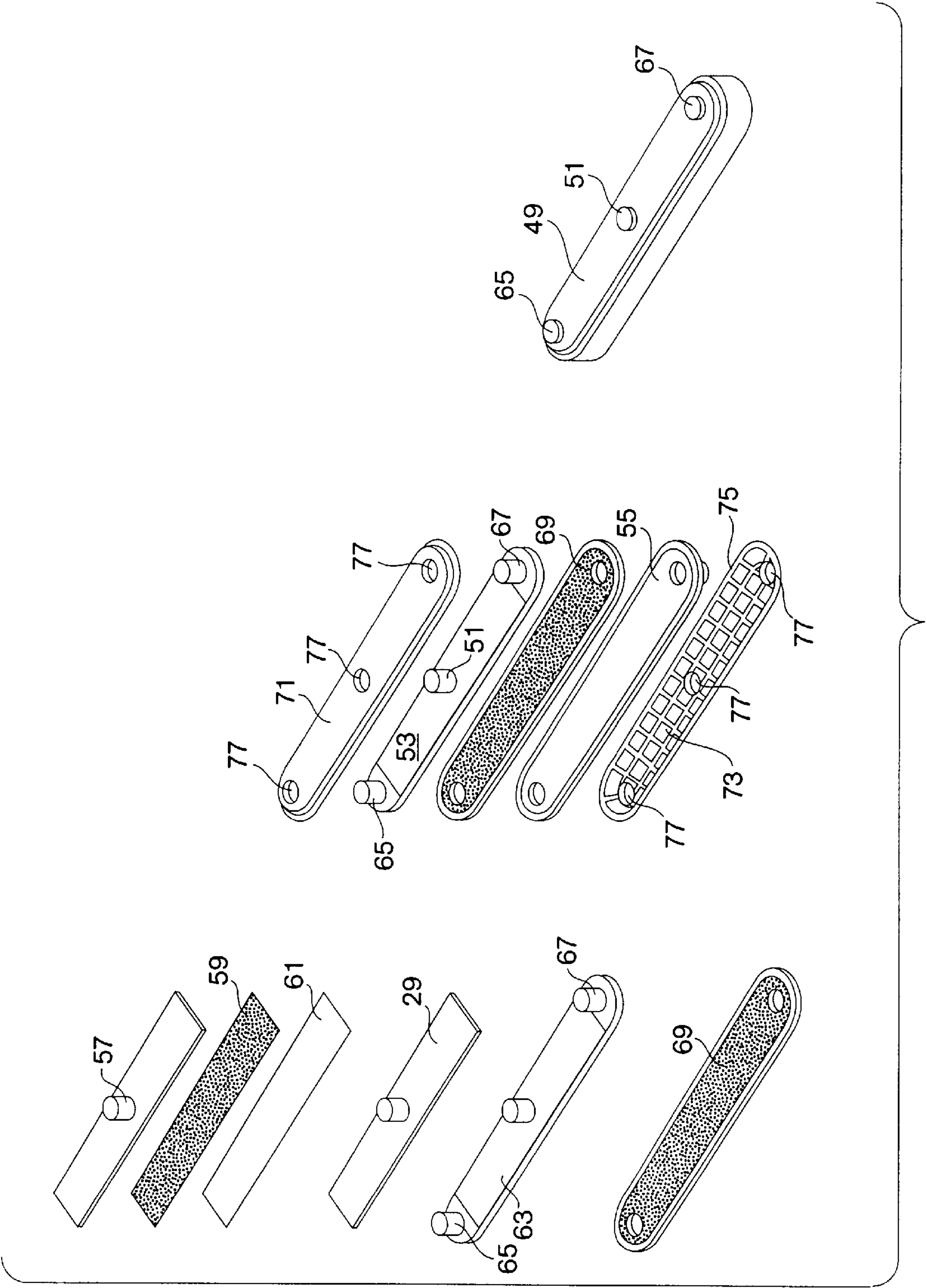


Fig. 3

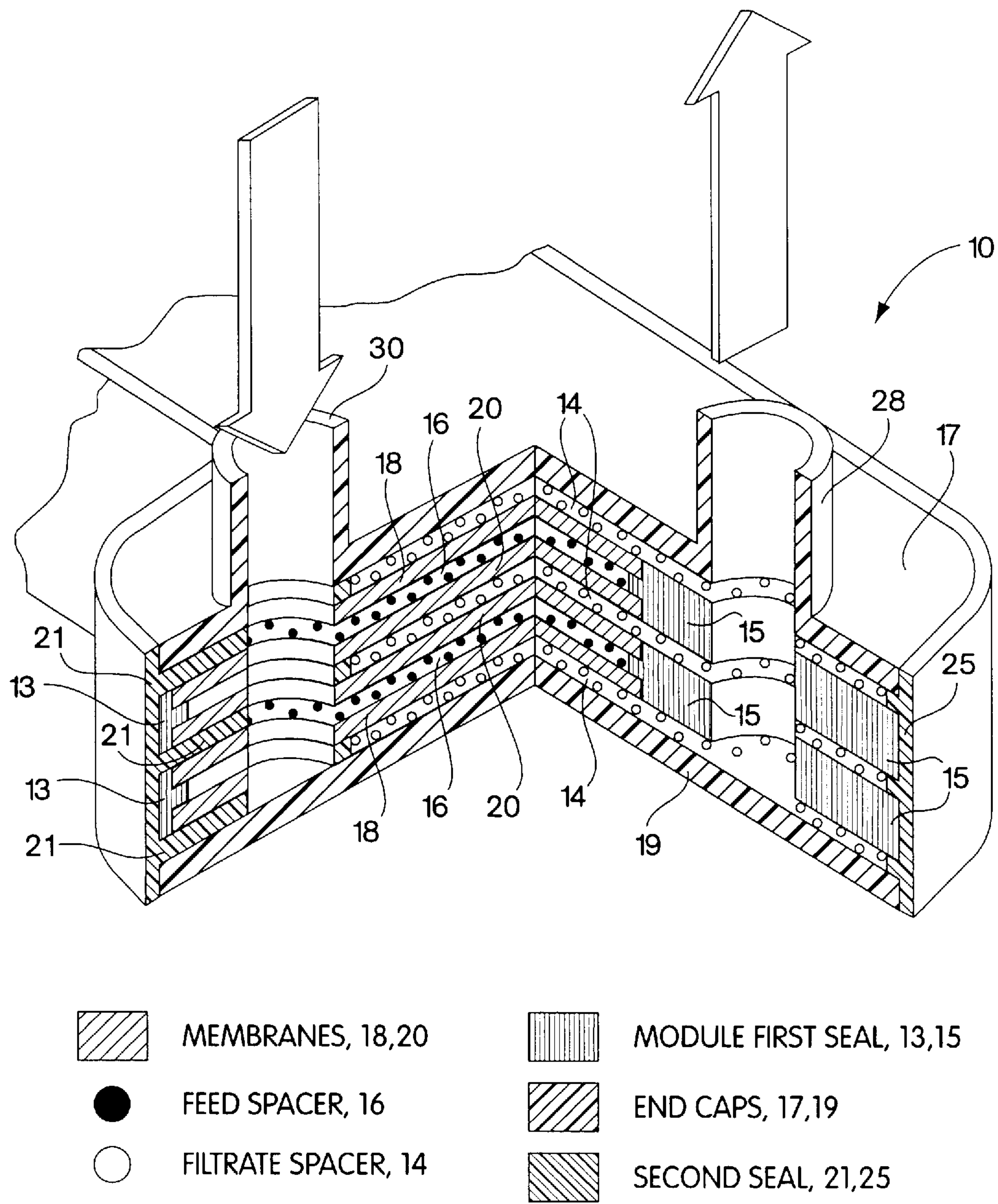


Fig. 4



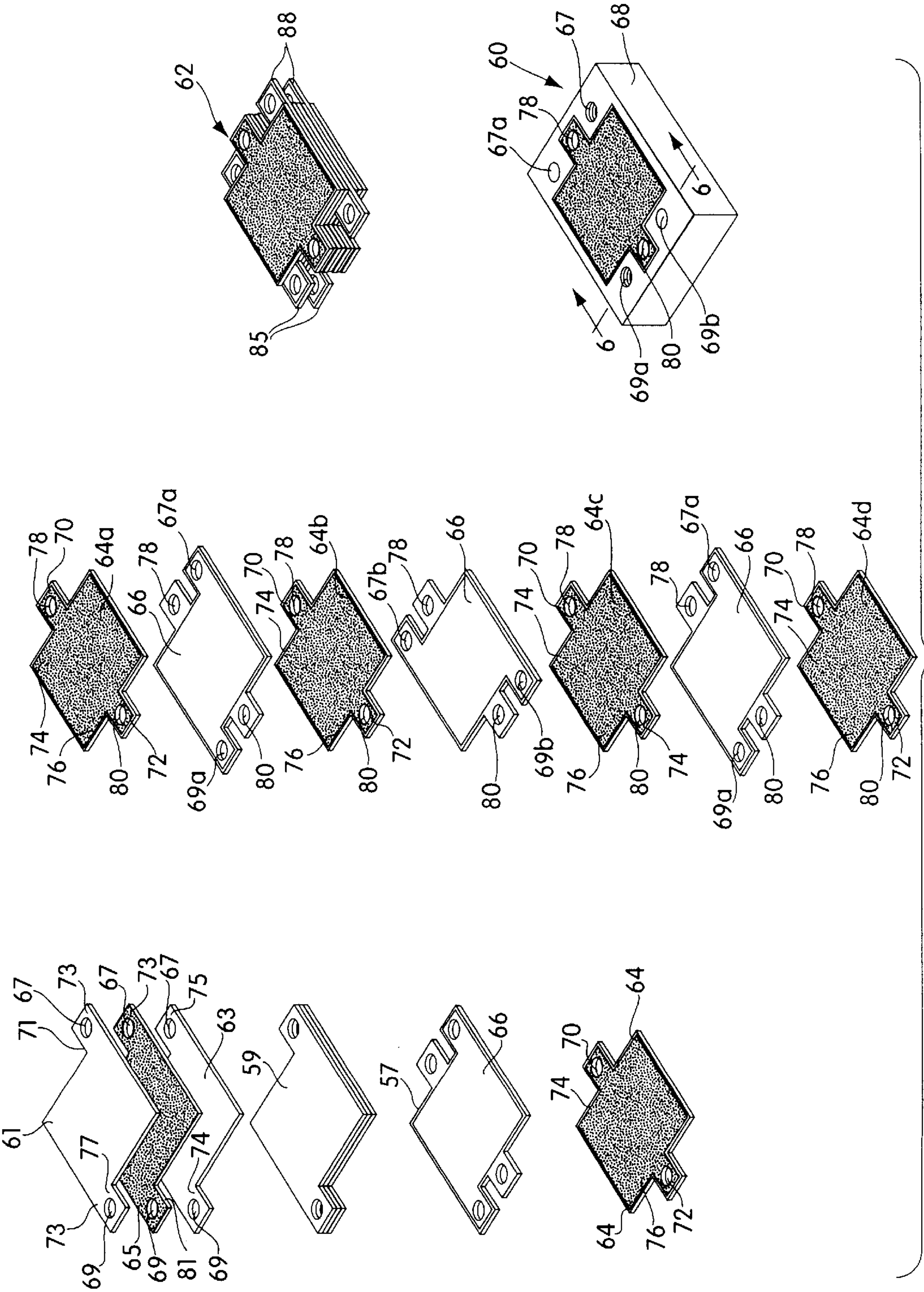


Fig. 5

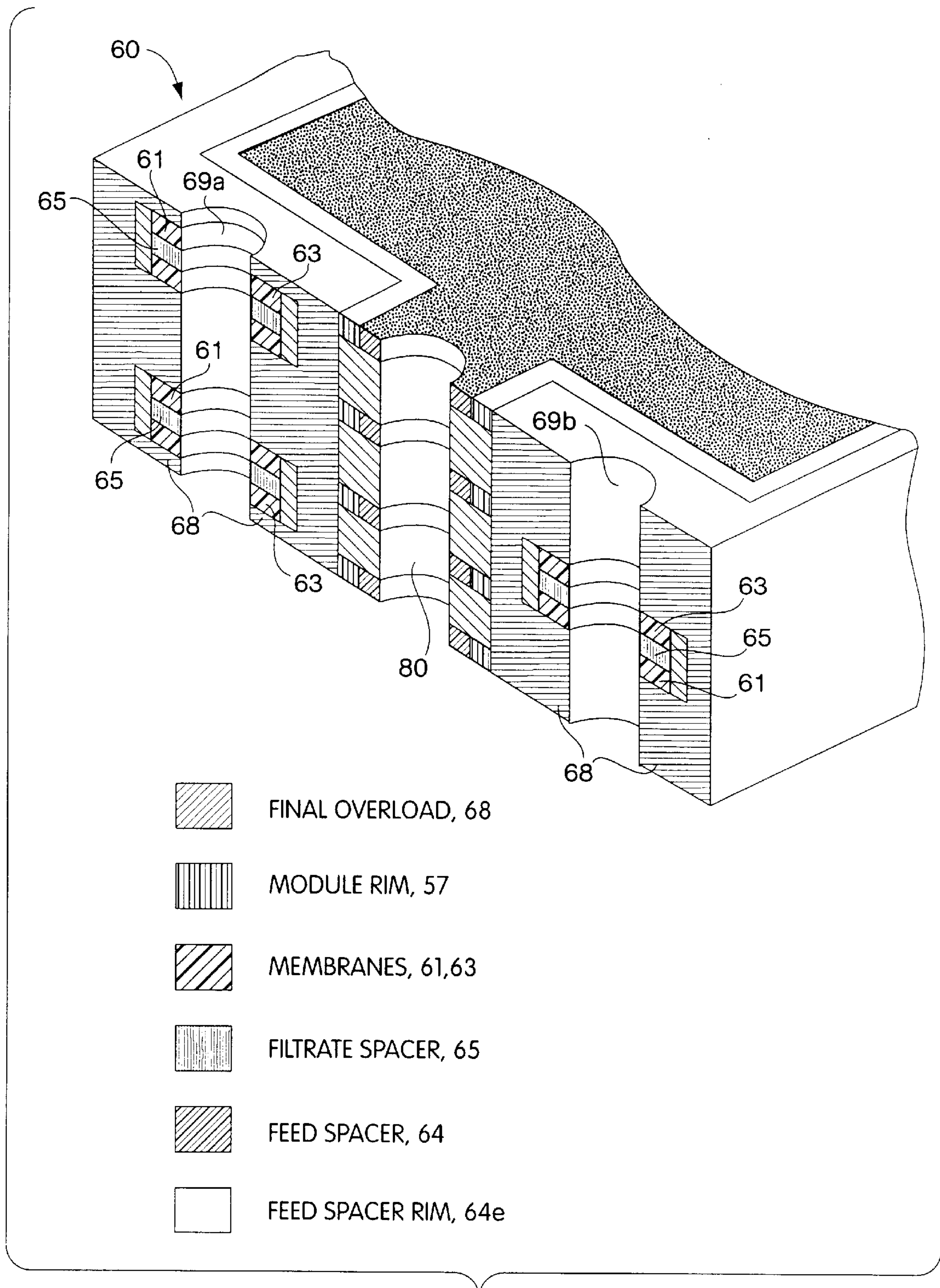
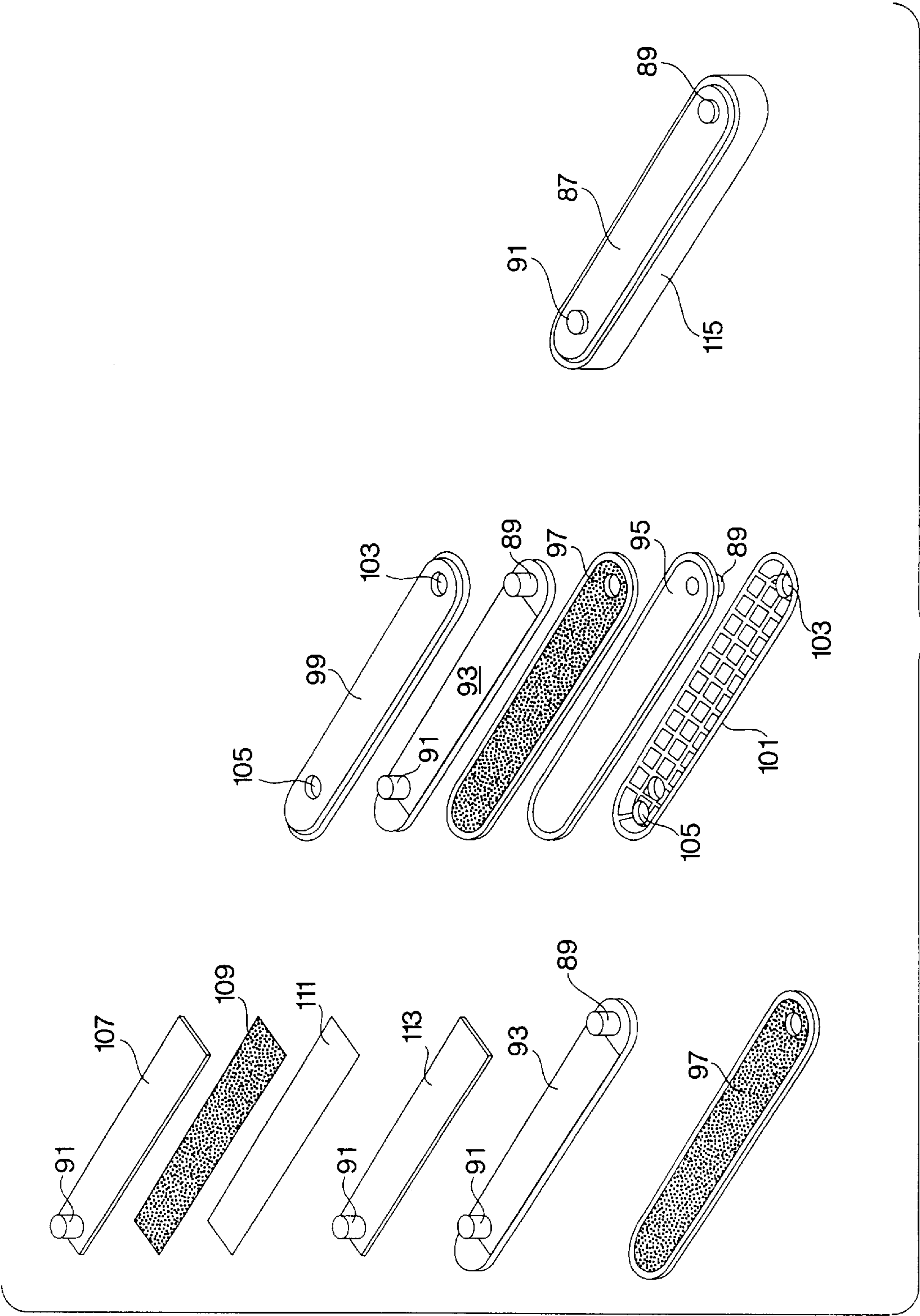


Fig. 6





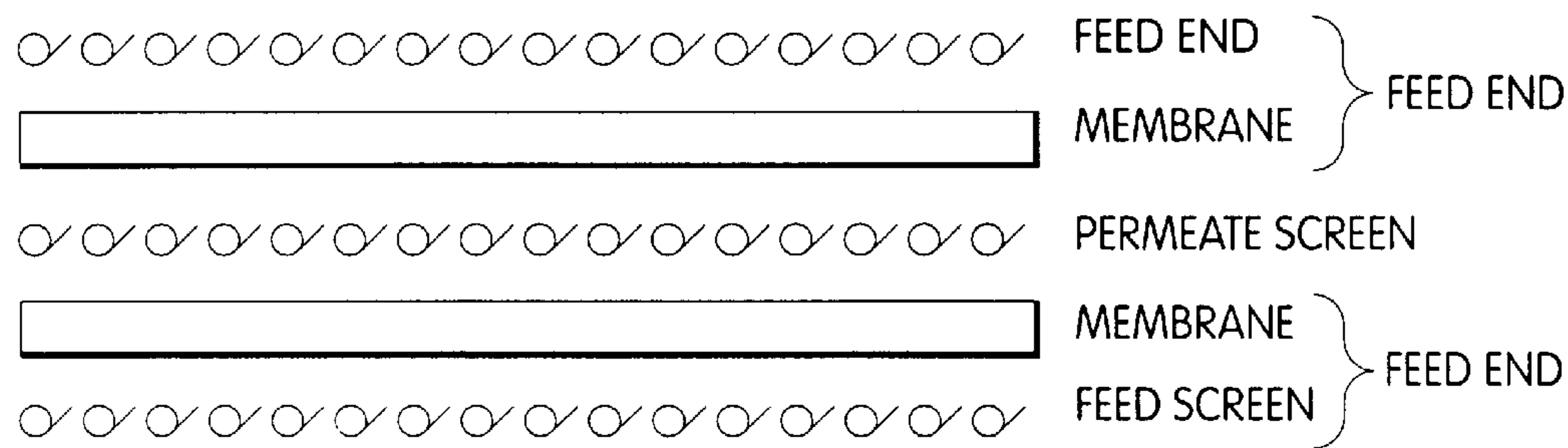


Fig. 8

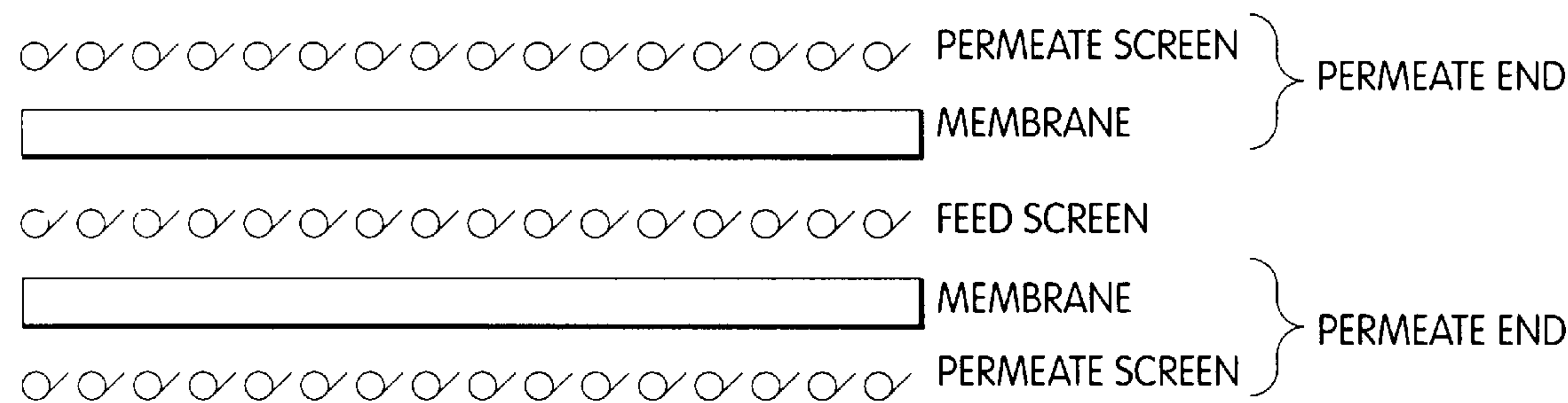


Fig. 9

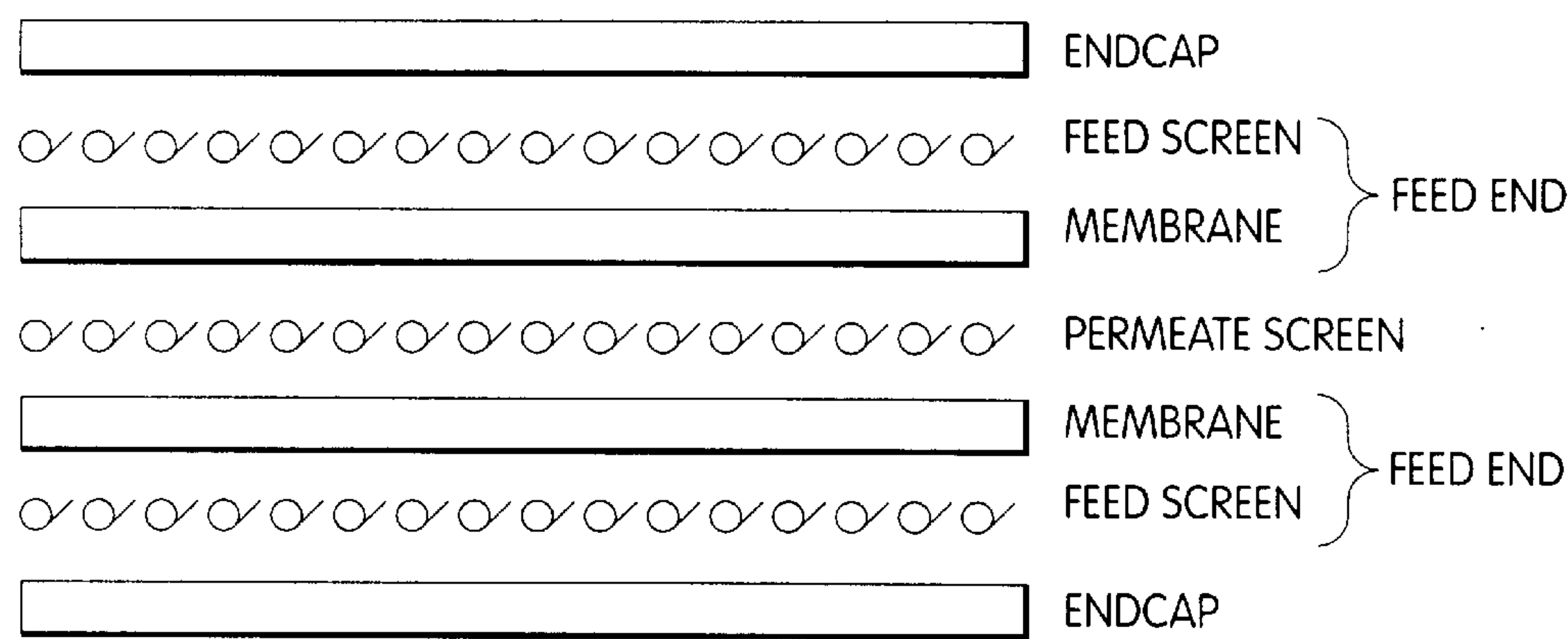


Fig. 10

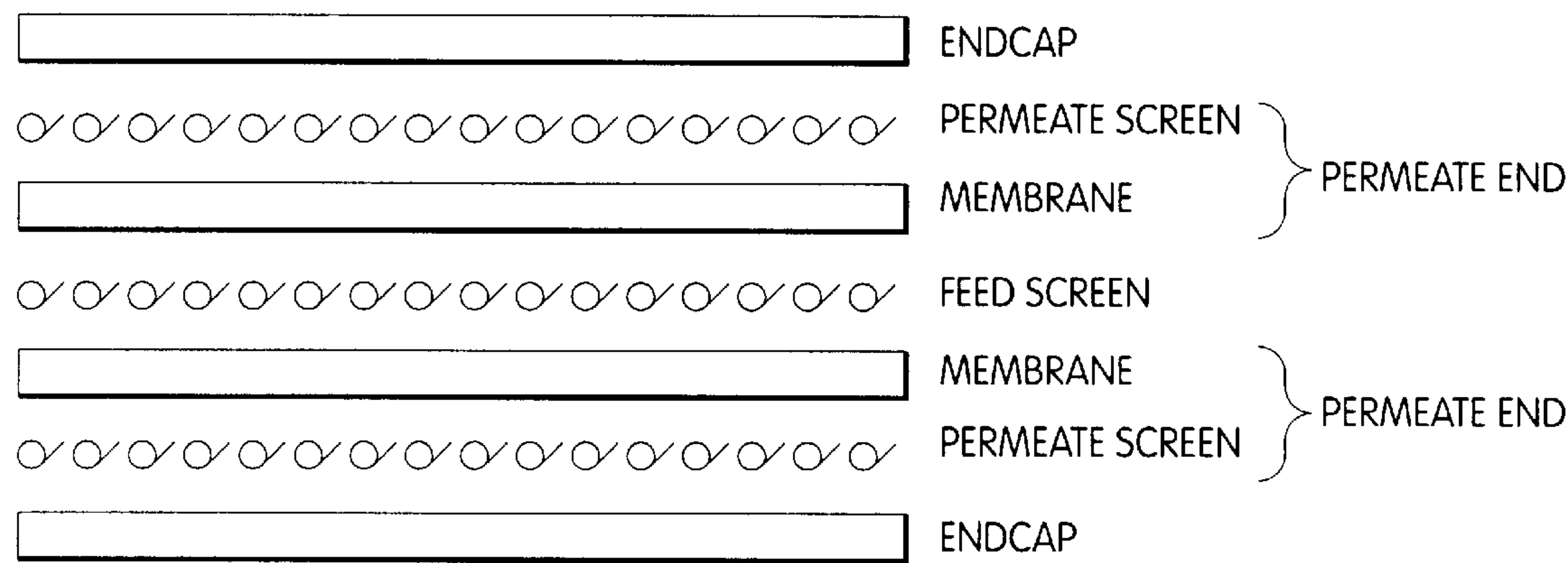


Fig. 11



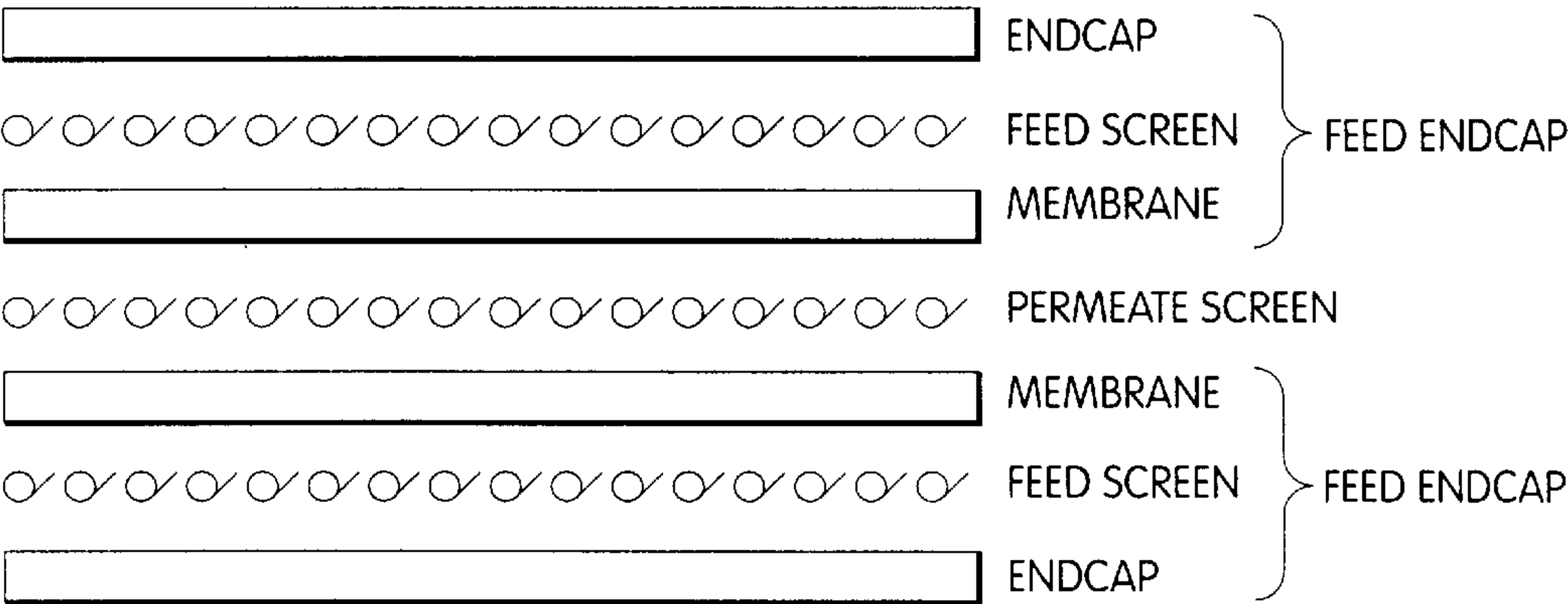


Fig. 12

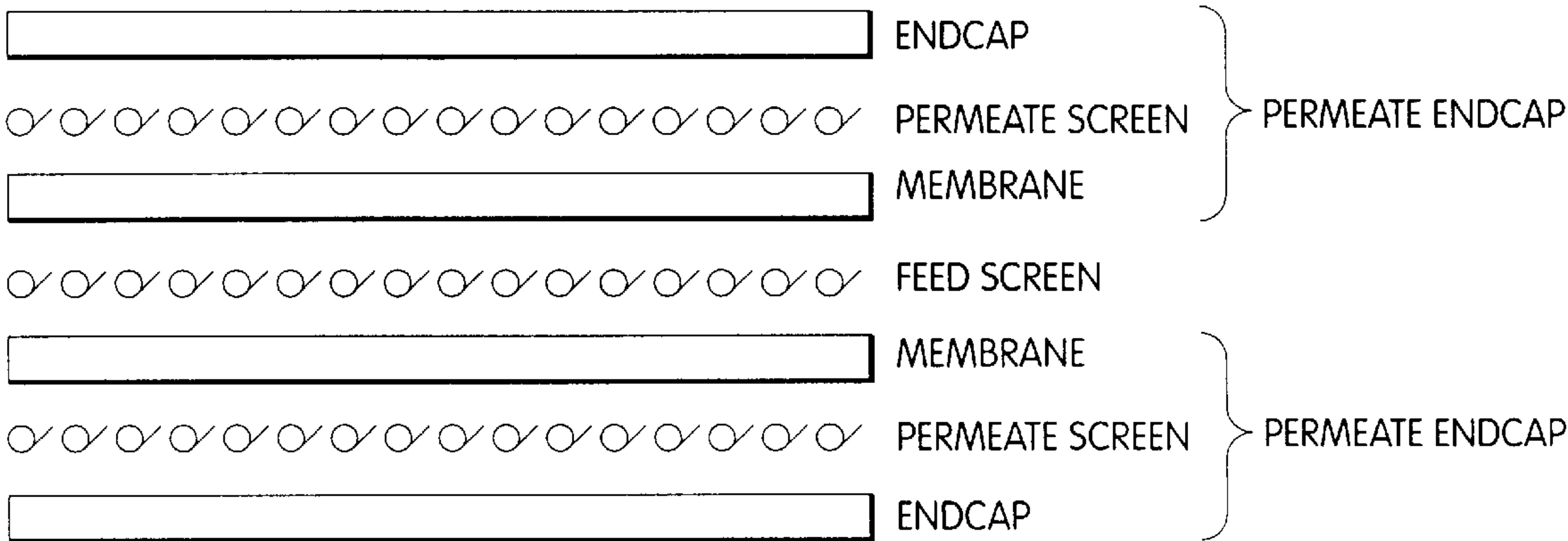


Fig. 13



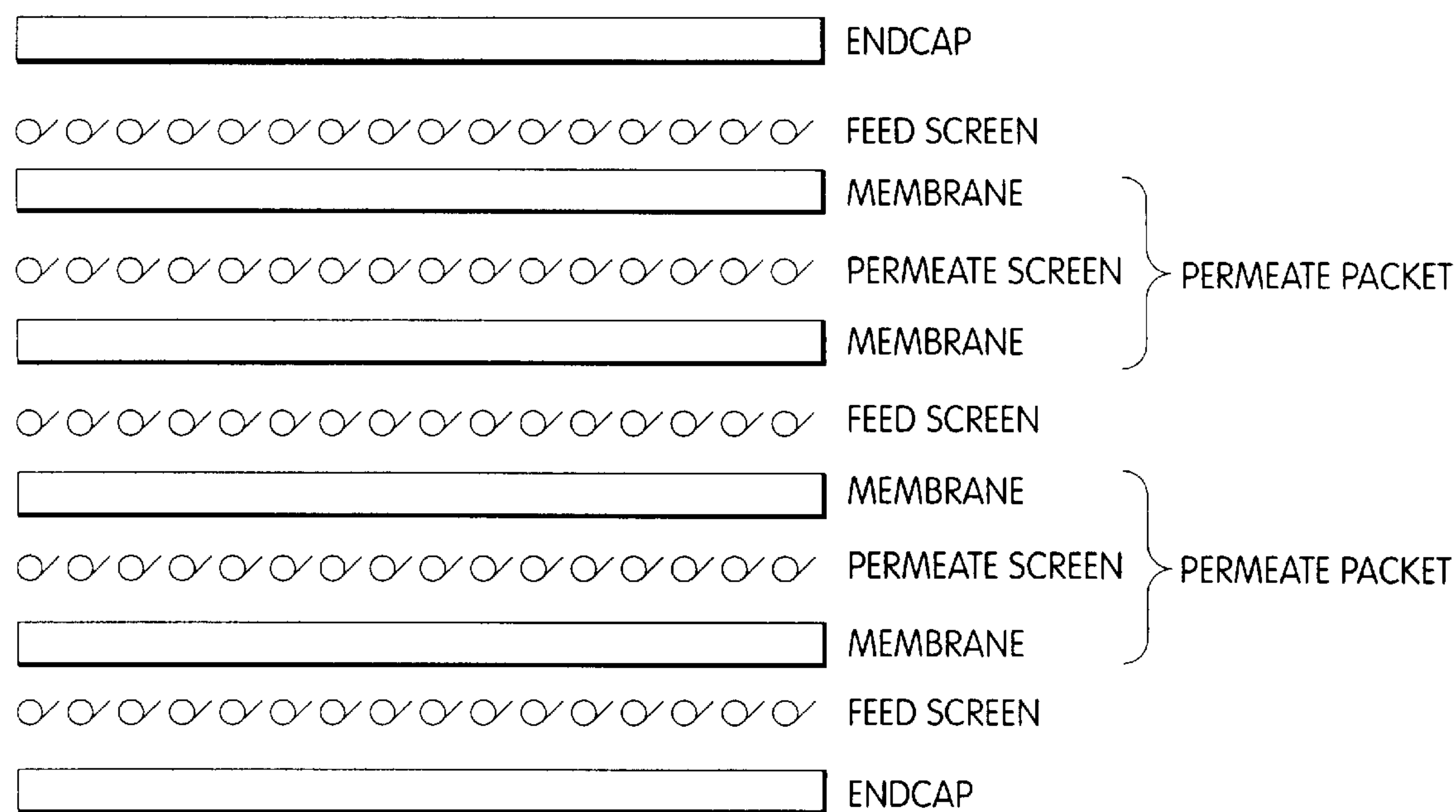


Fig. 16

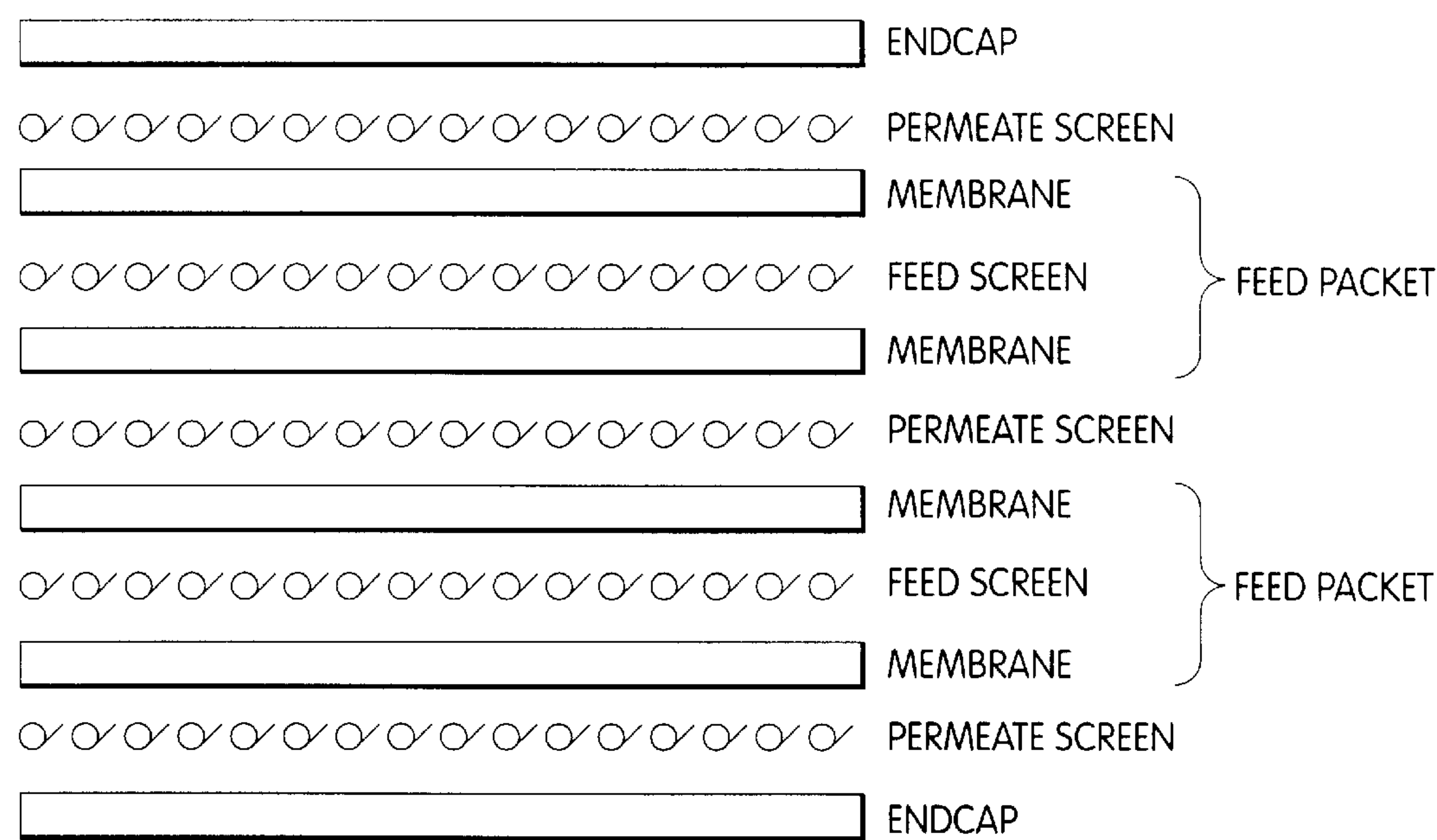


Fig. 17



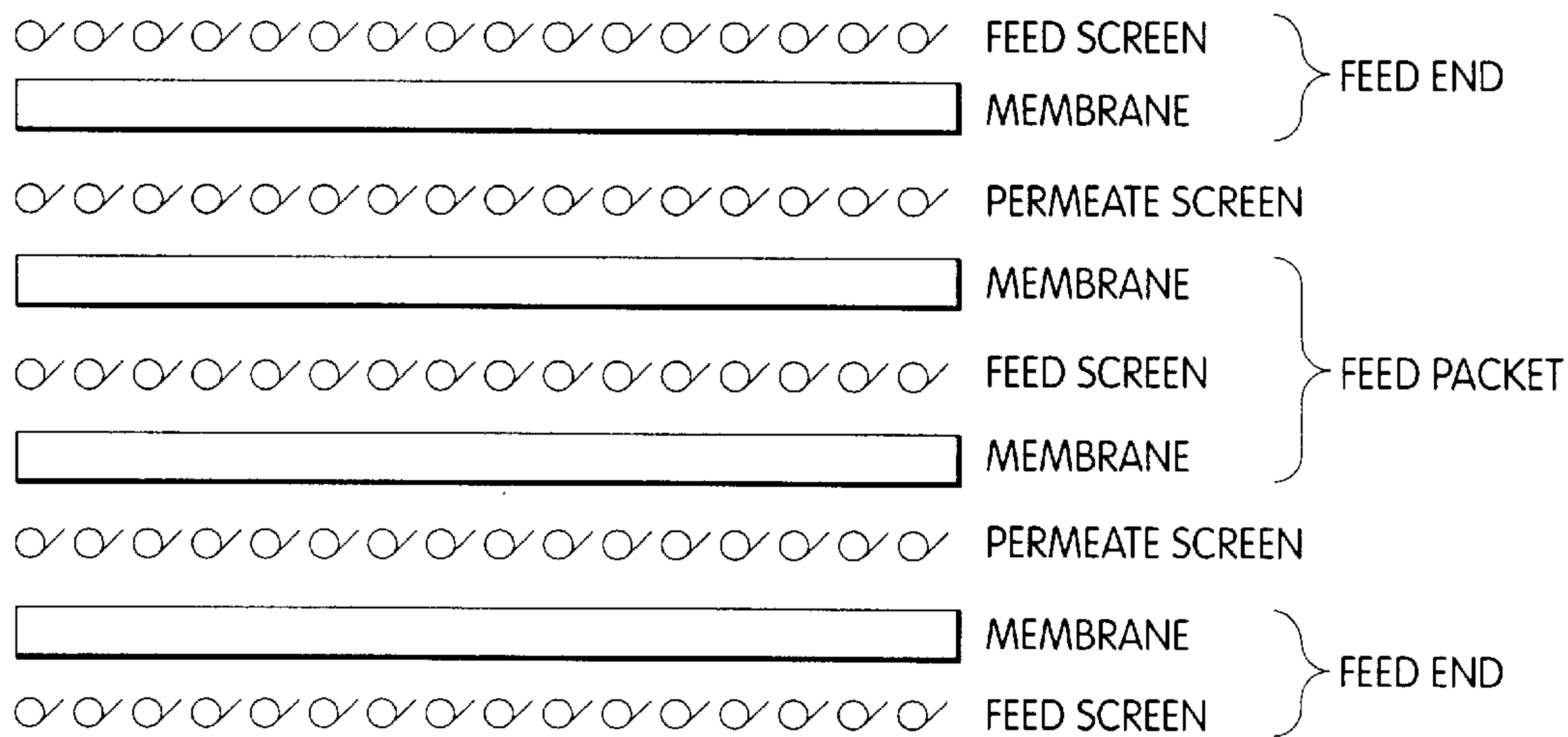


Fig. 18

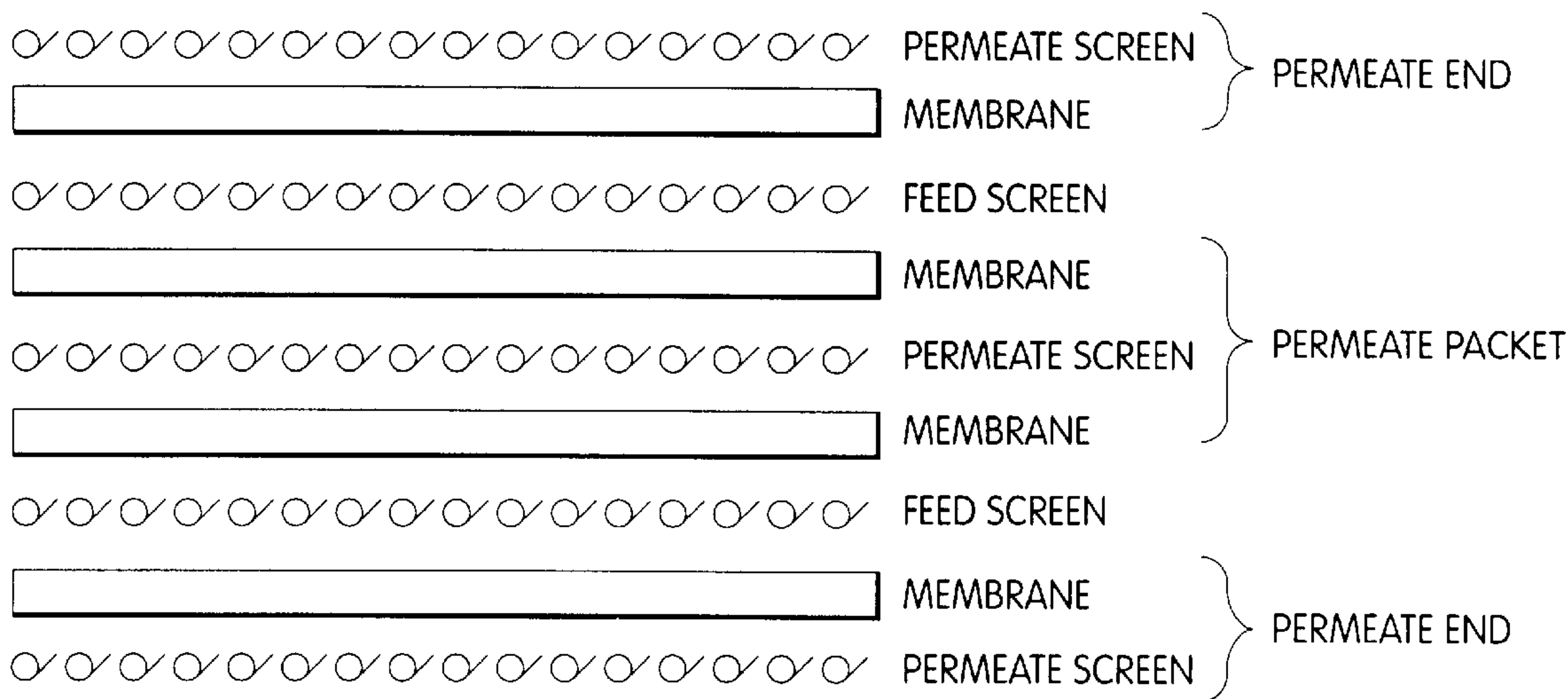


Fig. 19

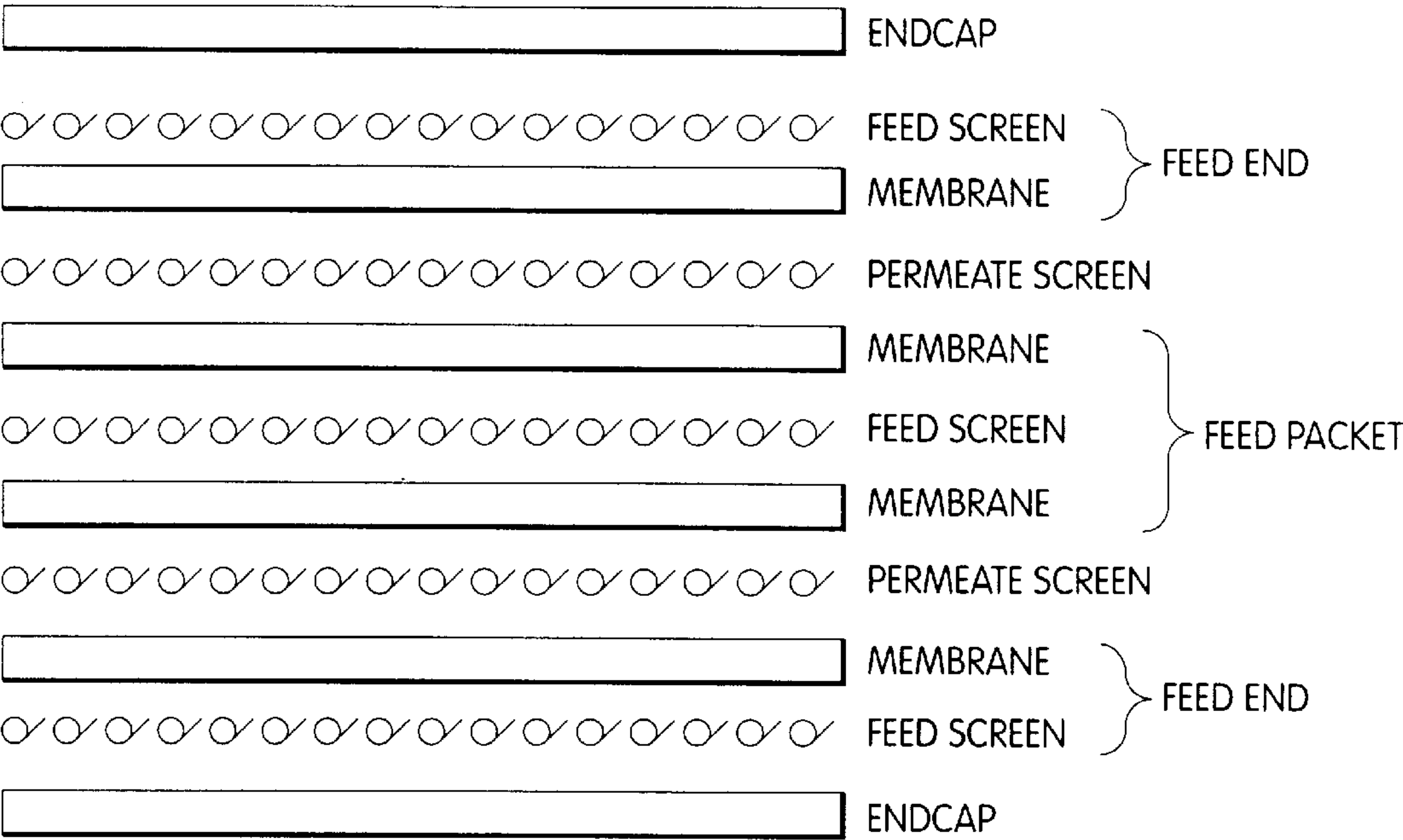


Fig. 20

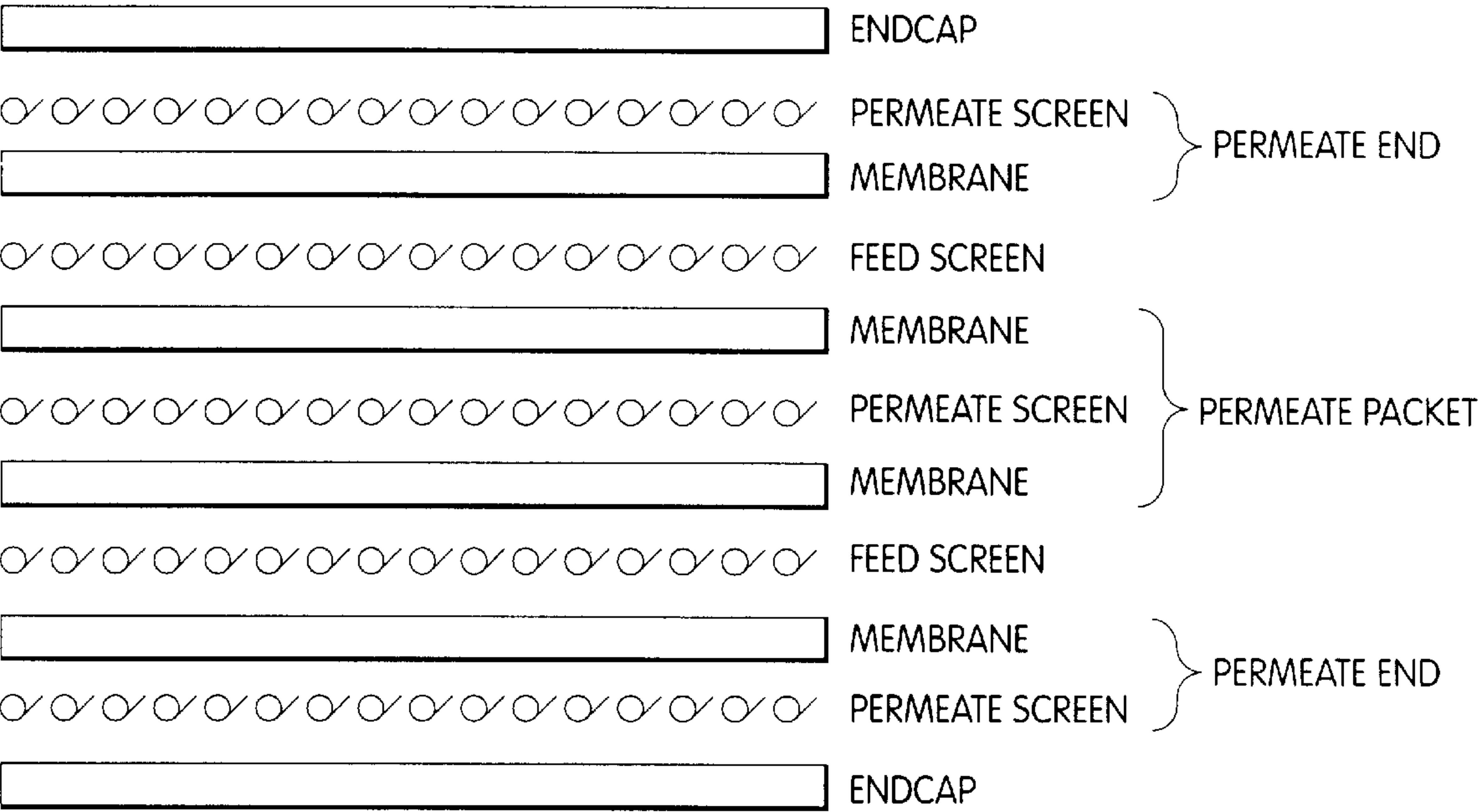


Fig. 21

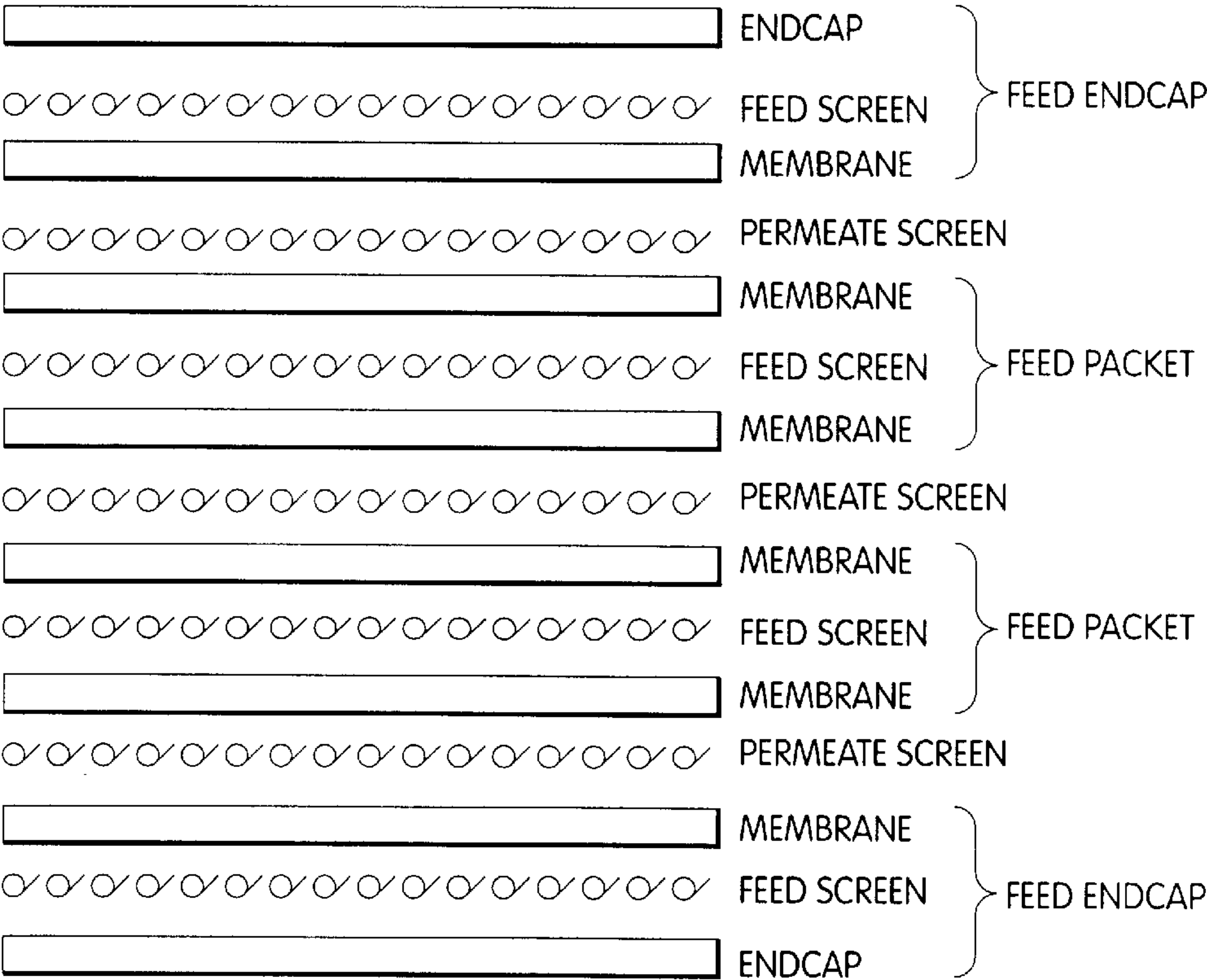


Fig. 22

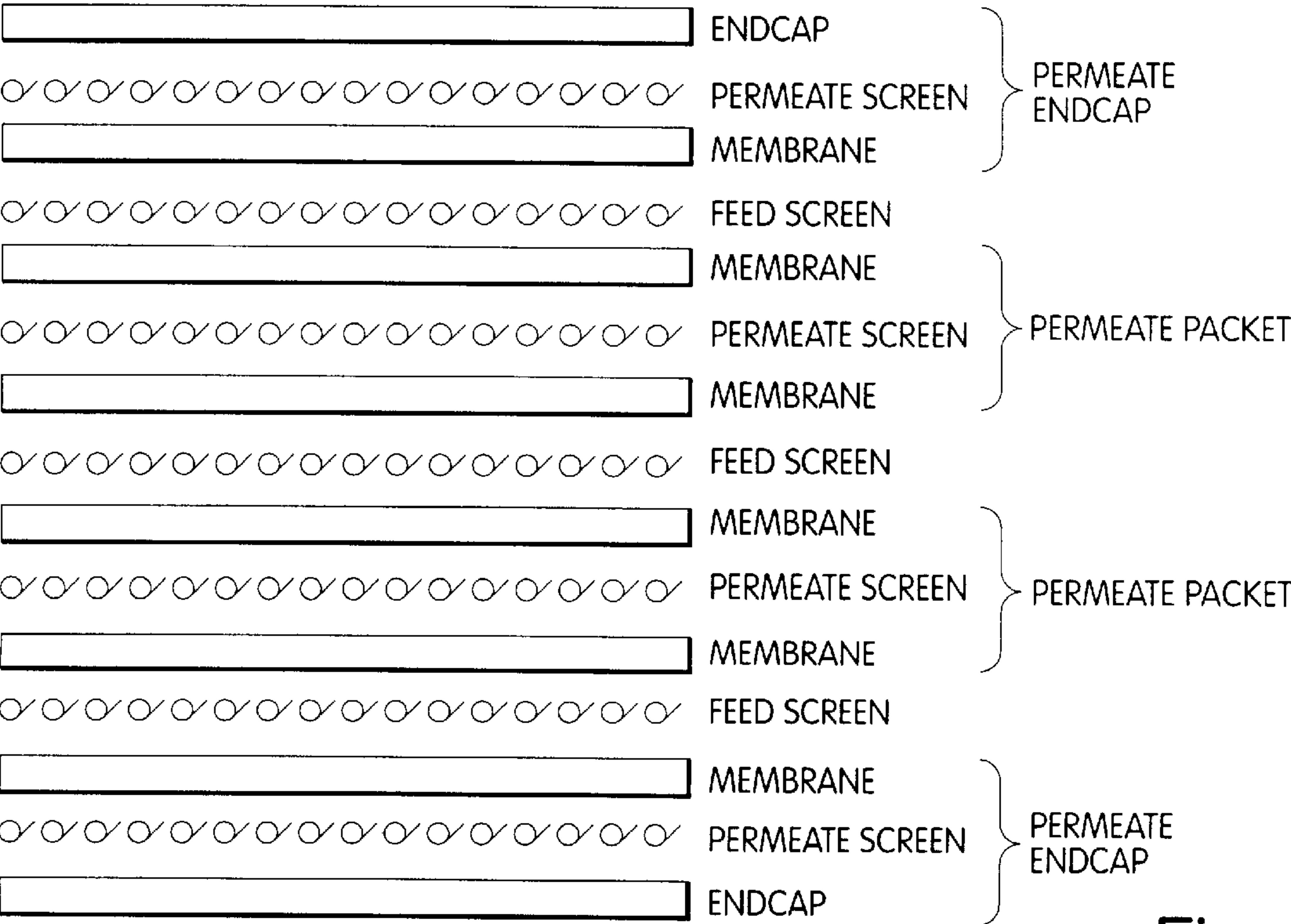


Fig. 23



## MEMBRANE FILTRATION APPARATUS

## BACKGROUND OF THE INVENTION

This invention relates to a membrane filtration apparatus for effecting filtration of a liquid composition wherein a feed liquid is introduced into the apparatus and a filtrate stream is removed from the apparatus. More particularly, this invention relates to a tangential flow membrane filtration apparatus or dead ended membrane filtration apparatus which are formed and selectively sealed by injection molding of a polymeric composition.

Prior to the present invention, liquids have been filtered within a plurality of filter modules that are stacked between manifolds or individually sealed to a manifold plate. Each module includes a one or more filter layers separated by appropriate spacer layers, such as screens, to permit liquid feed flow into the apparatus as well as filtrate flow from the apparatus. Filtration within the module can be conducted as a tangential flow process wherein incoming feed liquid is flowed tangentially over a membrane surface to form a retentate and a filtrate. Alternatively, filtration can be conducted as a dead end mode wherein all incoming feed liquid is passed through a membrane filter with retention of solids and other debris on the membrane filter. In this latter mode only a filtrate is recovered.

At the present time, filtrate is sealed from feed within a membrane filtration apparatus by sealing techniques utilizing potting adhesives, solvent bonding or heat sealing. In the case of a tangential flow filtration apparatus, filtrate is sealed from feed and retentate. Adhesives are undesirable since they have limited chemical compatibility, are a source of significant extractable species, introduce process control difficulties, impose bond strength limitations, impose use temperature limitations and increase process cycle time. Heat sealing is undesirable since its use imposes a limitation upon the thickness of the material being heat sealed. In addition, heat sealing is undesirable because it requires multiple steps, imposes material compatibility limitations and requires a substrate to effect heat sealing of filtration elements. Solvent bonding is undesirable since solvents impose environmental limitations and impose limitations on liquids to be filtered.

Accordingly, it would be desirable to provide a multilayer filtration apparatus which utilizes a plurality of filtration modules wherein the layers are appropriately sealed without the use of adhesive, solvent bonding or heat sealing. In addition, it would be desirable to provide a tangential flow or a dead ended filtration apparatus containing a plurality of filtration modules which can be formed into a stack and which can be appropriately sealed to define liquid flow paths within the stack in a one step sealing process.

## SUMMARY OF THE INVENTION

In accordance with this invention, a dead ended or tangential flow filtration apparatus is provided which includes a plurality of spaced-apart membranes and a plurality of spacer layers having channels or openings that promote liquid flow therethrough. The dead ended filtration apparatus are provided with at least one feed port and at least one filtrate port. The tangential flow filtration apparatus are provided with at least one feed port, at least one filtrate port and at least one retentate port. The membranes are included within modules each of which has at least one membrane layer and at least one spacer layer. The modules are pre-sealed by any convenient means so that they can be subsequently sealed with additional modules and spacer layers by

an insert molding process to form a membrane filtration apparatus formed from a stack of membranes and spacer layers which permits filtration of a liquid. An optional end cap can be provided at each end of the stack to assure liquid flow from the feed inlet to the retentate outlet, through a membrane, and to the at least one filtrate outlet. The spacer layers are appropriately sealed and side surfaces and end surfaces of the membrane filtration apparatus are appropriately sealed by insert molding with a molten polymeric composition which is caused to migrate into selected volumes of the spacer layers to effect sealing and to assure liquid flow within the stack, during use, from the feed inlet to the at least one filtrate outlet. In the case of a tangential flow filtration apparatus, liquid flow within the stack is assured by sealing the feed inlet and the retentate outlet from the filtrate outlet. Insert molding is accomplished by positioning the stack within an injection mold and injecting the molten polymeric composition into the mold to effect sealing in a manner that assures the desired liquid flow within the final membrane filtration apparatus during use. The spacer layers which accept filtrate are sealed by the plastic composition from a feed port extending into the stack so that the feed must pass through a membrane layer prior to entering a filtrate spacer layer. In addition, the spacer layers adjacent to the feed port which are designated to accept feed remain in liquid communication with the feed channel. Channels which accept either retentate or filtrate also extend into the stack. The channels which accept retentate are sealed from the filtrate spacer layers and are in fluid communication with the spacer layers which are also in fluid communication with the feed port. The port or ports which accept filtrate are sealed from the spacer layers which accept feed or retentate and are in fluid communication with the spacer layers that accept filtrate. The stack is also sealed in a manner so that liquid feed entering the feed spacer layers must pass through a membrane before entering a filtrate spacer layer. Prior to insert molding the stack, the stack is formed from single spacer layer units and multilayer modules which modules are partially presealed so that, in combination with the final insert molding step, the presealing assures the desired liquid flow through the final membrane filtration apparatus.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 and 1A illustrate the process for making one embodiment of a tangential flow filtration apparatus of this invention.

FIG. 2 illustrates the process for making a second embodiment of tangential flow filtration apparatus of this invention.

FIG. 3 illustrates the process for making a third embodiment of a tangential flow filtration apparatus of this invention.

FIG. 4 is a partial cross sectional view of one embodiment of a tangential flow filtration apparatus of this invention.

FIGS. 5 illustrates a process for making an alternative embodiment of a tangential flow filtration apparatus of this invention.

FIG. 6 is a partial cross-sectional view taken along line 6—6 of FIG. 5 of an embodiment of this invention which can be produced by the process illustrated in FIG. 5.

FIG. 7 illustrates a process for making a dead end flow filtration apparatus of this invention.

FIGS. 8—23 show labeled single layer and module configurations useful in the present invention.

## DESCRIPTION OF THE SPECIFIC EMBODIMENTS

The membrane filtration apparatus of this invention is formed from a stack of multilayer and monolayer elements



including working layers comprising membranes and spacer layers that provide a flow path for a liquid stream which is directed through the membranes as well as recovered retentate liquid streams which cannot pass through the membrane. The multilayer elements referred to herein as modules are formed from two or three components, at least one of which is a membrane layer and at least one of which is a spacer layer. The three component module is formed from two membrane layers, each positioned on one surface of a spacer layer. The monolayer comprises a spacer layer and can comprise a defined open volume or a porous single layer such as a screen. When utilizing an open volume as the spacer layer, it is formed with one or two mating rims forming the perimeter of the open volume which separates modules or separates a module and an end of the filtration apparatus. The modules can be formed from more than three layers, if desired. The spacer layer comprises an element having holes, channels or an open volume through which liquid can pass. The spacer layer is contiguous to or contacts a membrane through which liquid passes.

Modules forming a portion of the stack are presealed prior to being positioned within the stack and thereafter insert molded. The presealed configuration of the module will depend upon the position of the element within the stack and upon whether the filtration apparatus is to function in a tangential flow mode or in a dead end flow mode. The module can include either a feed spacer layer or a filtrate spacer layer. When the module includes the feed spacer layer, the module is presealed so that the feed spacer layer is open to the feed port and the retentate port in the filtration apparatus and is closed to the filtrate port or ports. When the module includes the filtrate spacer layer, the module is presealed so that the filtrate spacer layer is closed to the feed port and the retentate port, and is open to the filtrate port or ports. The monolayer elements within the stack forming the filtration apparatus comprise spacer layers. The membranes utilized in the stack can comprise ultrafiltration membranes, microporous membranes, nanofiltration membranes or reverse osmosis membranes. In a tangential flow filtration apparatus of this invention, the feed, retentate and filtrate ports are arranged so that incoming liquid feed to the filtration apparatus enters at least one feed channel, passes through the feed spacer layers and either passes through a membrane to form a filtrate stream or is retained by a membrane to form a retentate stream. The retentate stream is removed from the filtration apparatus through one or more retentate ports and the filtrate stream is removed from the filtration apparatus from one or more filtrate ports. If desired, multiple filtrate ports can be arranged to effect tangential flow on the filtrate side of the membranes. There is an inlet filtrate port(s) and an outlet filtrate port(s). In this case a portion of the filtrate can be recycled to the inlet filtrate port or ports as a means for controlling pressure on surfaces of the membranes within the stack. In a dead end flow filtration apparatus of this invention, the feed and filtrate ports are sealed from each other and only filtrate is recovered from the module. In the final step for forming the filtration apparatus of this invention, the stack of at least one module and at least one spacer layer is positioned within a mold and a flowable, e.g. liquid, polymeric composition is injected into the mold to seal the stacked elements together and to selectively migrate into either the feed spacer layers or the filtrate spacer layers to selectively seal the spacer layers thereby to assure liquid flow through the filtration apparatus described above.

Representative suitable membrane filters are ultrafiltration, microporous, nanofiltration or reverse osmo-

sis filters formed from polyvinylidene fluoride (PVDF), polysulfone, polyethersulfone, regenerated cellulose, polyamide, polypropylene, polyethylene, polytetrafluoroethylene, cellulose acetate, polyacrylonitrile, vinyl copolymer, cellulose acetate, polyacrylonitrile, vinyl copolymer, polycarbonate, PFA, blends thereof or the like. Suitable polymeric sealing compositions are those which provide the desired sealing configuration within the filtration apparatus and do not significantly degrade the elements forming the apparatus including the membranes, spacer layer ports and housing elements. In addition, the sealing composition should not degrade or provide a significant source of extractables during use of the apparatus. Representative suitable sealing compositions are thermoplastic polymer compositions including those based on polypropylene, polyethylene, PFA, PVDF, polysulfones, polyethersulfone, polycarbonate, acrylonitrile-butadienestyrene (ABS), polyester, blends thereof, filled or unfilled or the like.

Referring to FIGS. 1 and 1A, a filtration apparatus of this invention, **10** is formed from a plurality of modules **12** and a plurality of spacer layers **14**. The modules **12** are formed from a feed spacer layer **16** which can comprise a screen or the like and two membrane layers **18** and **20** and include filtrate ports **1** and **3**, feed port **5** and retentate port **7**. The module **12** is formed by placing the membrane layers **18** and **20** and spacer layer **16** in a mold and molding a plastic composition around the layers and selectively into the layers to form a first seal about the layers and to form a peripheral raised rib **9**. The module **12** is presealed in a manner which will be more fully described with reference to FIG. 4. The modules **12a** and **12b** as well as the filtrate screens **14** are positioned between end caps **22** and **24** within a mold and all of these elements are joined together to form a second seal by being insert molded within the mold. The end cap **22** is provided with filtrate ports **26** and **28**, feed port **30** and retentate port **32**. The module **10** is shown in FIGS. 1 and 1A is a tangential flow filtration module since it includes a retentate port **32** from which retentate is collected. A dead end filtration module is formed in the same manner but eliminating retentate ports **17** and **32**.

Referring to FIG. 2, the membrane filtration apparatus **40** is formed from two modules **42** and **44**, and a feed spacer layer **46**. In addition, the membrane filtration apparatus **40** can optionally include anti-deflection end caps **48** and **50** having ribbed interior surfaces **52**. The filtration module **40** is formed by insert molding Modules **42** and **44** include two filtrate outlet ports **54** and **56**, a feed inlet port **58** and a retentate outlet port **60**. The anti-deflection caps **48** and **50** include holes **62** through which extend the filtrate ports **54** and **56**, the retentate outlet port **60** and the feed inlet **58** for the modules **42** and **44** respectively. The modules **42** and **44** each are formed from an end cap **43**, filtrate screen **45** and a membrane **47**. In a first step, the end caps **43**, filtrate screen **45** and membrane **47** are placed into a mold and are presealed to form a first overmolded element **35**. The overmolded element **35** then is placed in a second mold and a plastic composition is molded about overmold **35** to form second overmolded element **37**, including retentate outlet port **60** and feed inlet port **58**. The feed spacer **46** is formed by molding a rib **39** about a screen having holes **41**.

Referring to FIG. 3, an alternative membrane filtration apparatus of this invention **49** utilizing a single filtrate exit port **51** on each module is illustrated. The membrane filtration apparatus **49** is formed from two modules **53** and **55**. The modules **53** and **55** are formed from a premolded cap **57**, a filtrate screen **59** and a membrane **61** which are molded



together to form a first overmolded **29**. A second overmolded element **63** is molded using the first overmolded element **29** to form a feed port **65** and a retentate port **67** and to preseal the modules **53** and **55**. A feed spacer layer **69** is positioned between the modules **53** and **55**. Anti-deflection caps **71** and **73** having ribbed interior surfaces **75** optionally can be utilized. The anti-deflection caps **71** and **73** each are provided with holes **77** which accommodate the ports **65**, **51** and **67**. The filtration apparatus **49** is formed by insert molding.

Referring to FIG. 4, the sealing arrangement for a multilayer embodiment of the membrane filtration apparatus **10** of FIGS. 1 and 1A is illustrated. Prior to being stacked, the module formed of multilayer elements comprising the two membranes **18** and **20** and the feed spacer **16** is presealed in the area adjacent to feed port **30** by seal **13** which seals the membranes **18** and **20** and the spacer **16** together while leaving spacer **16** in open fluid communication with the feed port **30**. The modules are presealed differently at the area adjacent the filtrate ports **26** (FIG. 1A) and **28** as compared to the areas adjacent the feed port **30** and the retentate port **32** (FIG. 1A). As shown in FIG. 4, the module is sealed in areas **15** to permit liquid communication between the filtrate layers **14** with the filtrate channels **26** or **28**. The area adjacent the retentate port **32** (FIG. 1A) is sealed in the same manner as the area adjacent the feed port shown in FIG. 4. By presealing the modules in this manner, they can be stacked and insert molded to form the filtration apparatus of this invention. The stack of elements, in the final insert molding step are positioned between two end caps **17** and **19** which seal the top and bottom of the stack. Thereafter, a molten polymeric composition is injected into the mold containing the stack to seal the sides of the stack in area **21** adjacent the feed port **30** and to prevent leakage from module **10**. The molten polymeric composition also seals the feed spacer layers **16** from fluid communication with the filtrate ports **26** and **28** in areas **25** and to prevent leakage from module **10**. The insert molding step is conducted so as to avoid closing the filtrate spacer layers **14** from fluid communication with the filtrate ports **26** and **28**. Thus, the molding polymeric composition **25** does not extend a significant distance into the filtrate spacers **14** to maintain this desired open fluid communication with the filtrate ports **26** and **28**. By operating in this manner, a stack of filtration elements can be assembled and selectively sealed in a one step insert molding process.

Referring to FIG. 5, the membrane filtration apparatus **60** is formed from a stack **62** of monolayer feed spacer layers **64**, labeled specifically as **64a**, **64b**, **64c** and **64d**, and modules **66** which stack has been insert molded to form the overmold **68**. The overmold **68** seals the side, top and bottom surfaces of filtration apparatus **60**. The overmold **68**, formed by insert molding, also seals the internal surfaces of the stack **62** to effect the desired liquid flow within the stack described above is described below with reference to FIG. 6.

The module **66** is formed from an unbonded laminate **59** which is formed from two filter (membrane) layers **61** and **63**, filtrate spacer, e.g. screen **65**. The molded rim **57** extends about the periphery of the module **66** and serves to accommodate feed spacer layers **64** with a molded rim **64e** on both of its surfaces. Each filter layer **61** and **63** and filtrate spacer layer **65** is provided with two filtrate ports **67** and **69** which are positioned diagonally to each other and are positioned within tab sections **71**, **73**, **75**, **77**, **79** and **81**. The tab sections are positioned on each of these layers. The tab sections **71**, **73**, **75**, **77**, **79** and **81** extend away from central portions of each of these layers so that the ports located

therein can be easily accessed. The feed spacer layers **64a**, **64b**, **64c** and **64d** are also provided with tab sections **70** and **72** positioned on opposing surfaces **74** and **76** of each spacer layer. An opening **78** on one of the tab sections **70** forms part of a feed port within the apparatus **60** while the opening **80** on the other tab **72** forms part of a retentate port within the apparatus **60**. The spacer layers **64a**, **64c**, **64b** and **64d** can function as either feed spacer layers or as filtrate spacer layers by reversing the feed and filtrate ports. If spacer layers **64** are filtrate spacer layers, then spacer layer **65** becomes a feed spacer. A significant advantage derived from this embodiment is due to the spaced apart filtrate tab sections **83** and **85** formed respectively from tab sections **73**, **75** and **71** or **79**, **77** and **81**. By alternating their positions, more precise control of molten sealing polymeric composition flow can be attained. That is, the filtration element **60** can be more easily selectively sealed since flow of molten polymer composition in the area of each tab section and, therefore each filtrate port can be more easily controlled while minimizing an undesirable sealing configuration within the feed port or retentate port formed by opening **78** or the retentate port formed by openings **80**.

Referring to FIG. 6, the sealing arrangement for the membrane filtration apparatus **60** of FIG. 5 is shown. The module **66** (FIG. 5) formed of membranes **61** and **63** and filtrate spacer **65** are presealed so that filtrate ports **69a** and **67a** are in fluid communication with the filtrate spacers **65** but not in fluid communication with retentate port **80** or feed port **78** (FIG. 5). The final overmold **68** preserves this sealing arrangement and prevents leakage from module **60**.

Referring to FIG. 7, a dead end flow filtration apparatus **87** includes a feed port **89** and a filtrate port **91**. The filtration apparatus **87** is formed from two multilayer modules **93** and **95**, each of which is formed with the feed port **89** and the filtrate port **91**; a spacer layer **97**; and two antideflection caps **99** and **101** each are provided with a feed port clearance hole **103** and a filtrate port clearance hole **105**. The multilayer modules **93** and **95** can be formed in two steps. In a first step, a premolded end cap **107**, a filtrate screen **109** and a membrane **111** are sealed together to form a first overmolded element **113**. In a second step, the first overmolded element **113** is overmolded to form multilayer modules **93** and **95** with feed ports **89**. The filtration apparatus **87** is formed by sealing together end caps **99** and **101**, spacer layer **97** and modules **93** and **95** by an insert molding step which forms outside seal **115** and seals filtrate port **91** from feed port **89** and to allow feed to pass through the membrane **109** to form filtrate.

In FIGS. 8–23, the term, “permeate” is used interchangeably with the term, “filtrate”. Also, the term, “screen” is used interchangeably with the term, “spacer layer”.  $n$  is an integer equal to or greater than one.

Referring to FIG. 8, an embodiment is shown having  $n$  permeate screens and  $n$  plus 1 modules consisting of a feed screen and a membrane. Filtration can also be effected with only 1 permeate screen and 1 module consisting of a feed screen and a membrane.

Referring to FIG. 9, an embodiment is shown having  $n$  feed screens and  $n$  plus 1 modules consisting of a permeate screen and a membrane. Filtration can also be effected with only 1 feed screen and 1 module consisting of permeate screen and membrane.

Referring to FIG. 10, an embodiment is shown having 2 end caps,  $n$  permeate screens and  $n$  plus 1 modules consisting of a feed screen and a membrane.

Referring to FIG. 11, an embodiment is shown having 2 end caps,  $n$  feed screens and  $n$  plus 1 modules consisting of a permeate screen and a membrane.



Referring to FIG. 12, an embodiment is shown having 1 permeate screen and 2 modules consisting of a feed screen, a membrane and an end cap.

Referring to FIG. 13, an embodiment is shown having 1 feed screen and 2 modules consisting of a permeate screen, a membrane and an end cap.

Referring to FIG. 14, an embodiment is shown having n modules consisting of a permeate screen and two membranes and n plus 1 feed screens.

Referring to FIG. 15, an embodiment is shown having n modules consisting of a feed screen and two membranes and n plus 1 permeate screens.

Referring to FIG. 16, an embodiment is shown having 2 end caps, n modules consisting of a permeate screen and two membranes and n plus 1 feed screens.

Referring to FIG. 17, an embodiment is shown having n modules consisting of a permeate screen and two membranes, n plus 1 feed screens and 2 end caps.

Referring to FIG. 18, an embodiment is shown having n permeate screens and n minus 1 modules consisting of a feed screen, two membranes and two modules consisting of a feed screen and a membrane.

Referring to FIG. 19, an embodiment is shown having n feed screens, n minus 1 modules consisting of a permeate screen and two membranes and two end modules consisting of a permeate screen and a membrane.

Referring to FIG. 20, an embodiment is shown having 2 end caps, n permeate screens and n minus 1 modules consisting of a feed screen and two membranes and two end modules consisting of a feed screen and a membrane.

Referring to FIG. 21, an embodiment is shown having 2 end caps, n feed screens, n minus 1 modules consisting of a permeate screen and two membranes and two end modules consisting of a permeate screen and a membrane.

Referring to FIG. 22, an embodiment is shown having 2 end modules consisting of an end cap, a feed screen and a membrane, n permeate screens and n minus 1 modules consisting of a feed screen and two membranes.

Referring to FIG. 23, an embodiment is shown having 2 end modules consisting of an end cap, a permeate screen and a membrane, n feed screens and n minus 1 modules consisting of a permeate screen and two membranes.

The following examples illustrate the present invention and are not intended to limit the same.

EXAMPLE I

This example illustrates a method for preparing a tangential flow filtration apparatus of this invention utilizing insert molding to effect final sealing within a stack of filtration modules provided with end caps and monolayer spacer layers.

End Cap

The end caps are molded from polypropylene homopolymer. They are molded in an aluminum mold using an injection molding machine. The mold is preheated to 130 F. and clamped at 10,000 pounds of force. The polypropylene homopolymer, at 500 F., is injected with a pressure of 3000 psi. The resultant end cap has two female Luer port connections.

First Overmold

In preparation for the next molding step a piece of polypropylene permeate screen and a piece of Millipore Biomax®10 (polyethersulfone on nonwoven polypropylene), available from Millipore Corporation, Bedford, Mass. die cut using a steel rule die. The permeate

screen, a twill weave, has a thickness of 0.012 inch and has a strand count of 71×71 strands/inch.

The end cap, permeate screen and piece of Biomax®10 membrane are placed together in an aluminum mold to create the first subassembly referred to as the First Overmold. The mold is aluminum and incorporates a sliding insert which exerts a clamping force on the assembly while molding. The mold is preheated to 130 F. and clamped at 10,000 pound of force. The insert is clamped at 1500 pounds of force. The polypropylene homopolymer, at 500 F., is injected with a pressure of 3000 psi. The resultant structure is the First Overmold subassembly.

Second Overmold

In this step the First Overmold subassembly is modified by the addition of feed and retentate Luer ports and by adding a bonding surface around the perimeter of the membrane. This is done by placing the first overmold subassembly in an aluminum mold with a sliding insert. The mold is preheated to 130 F. and clamped at 10,000 pounds of force. The insert is clamped at 1500 pounds of force. The polypropylene homopolymer at 500 F., is injected with a pressure of 3000 psi.

The resultant structure is the Second Overmold subassembly. This second overmold process is then repeated for another subassembly.

Feed Spacer

The feed spacer is woven polypropylene screen to which a solid polypropylene perimeter is added. The twill woven screen has a thickness of 0.016 inch and features a strand count of 51×51 threads/inch.

A steel rule die is used to cut the perimeter of the screen and two 0.156 inch diameter alignment holes in either end of the screen. The spacer is created using an aluminum mold with a sliding insert. The mold is preheated to 130 F. and clamped at 10,000 pounds of force. The insert is clamped at 1500 pounds of force. The polypropylene homopolymer polymer, at 500 F., is injected with a pressure of 3000 psi to form the Feed Spacer.

Deflection Cap

The polymer used for the deflection caps is a 30% glass filled polypropylene. The caps are molded in an aluminum mold and preheated to 130 F. and clamped at 10,000 pounds of force and injected with pressure of 4,500 psi.

Final Overmold

A feed spacer is sandwiched between two of the second overmold assemblies together with two deflection caps. The final unit is created by overmolding this assembly using molten polypropylene homopolymer to encapsulate/bond the perimeter. This is accomplished in an aluminum mold with a sliding insert. The mold is preheated to 130 F. and clamped at 10,000 pounds of force. The insert clamps the assembly at 1500 pounds of force. The polypropylene homopolymer, at 500 F., is injected with a pressure of 3000 psi.

Finished Unit

The finished unit has 19 cm<sup>2</sup> of Biomax®10 membrane area. Hydraulic testing of this module gave the following results:

Wetted Air Integrity	0 SCCM @ 30 psi
Feed Channel Pressure Drop	10 psi @ 50 ml/min Q <sub>f</sub>
Water Permeability	19 LMH/psi
6% BSA, 8 C flux	127 LMH @ Q feed, 38 cc/min. + TMP, 45 psi

What is claimed is:

1. A membrane filter apparatus of unitary sealed construction for carrying out tangential flow filtration comprising:



at least one module layer including at least one membrane filter and at least one first spacer layer,  
 said apparatus having at least three ports,  
 at least one of said ports being a feed port, at least one of  
 said ports being a retentate port and at least one of said  
 ports being a filtrate port, said feed and retentate ports  
 being in fluid communication with each other, each  
 filtrate port being sealed from fluid communication  
 with both said feed port and said retentate port,  
 said at least one module layer being sealed to form a  
 perimeter seal about said at least one spacer layer and  
 said at least one membrane filter and to form a first port  
 seal which isolates said at least one filtrate port from  
 said feed and retentate ports,  
 at least one second spacer layer positioned adjacent each  
 said at least one module layer and being insert molded  
 to form a perimeter seal about the periphery of said at  
 least one second spacer layer and said at least one  
 module layer which seals said at least one feed port and  
 said at least one retentate port from said at least one  
 filtrate port and which permits fluid flow within said  
 apparatus to introduce a feed into said apparatus and to  
 remove a retentate and a filtrate from said apparatus.

2. The apparatus of claim 1 wherein said at least one  
 module layers comprises one feed screen as the at least one  
 first spacer layer and one membrane filter.

3. The apparatus of claim 1 wherein said at least one  
 module layers comprises one filtrate screen as the at least  
 one first spacer layer and one membrane filter.

4. The apparatus of claim 2 having an end cap at each end  
 of said membrane filter apparatus.

5. The apparatus of claim 3 having an end cap at each end  
 of said membrane filter apparatus.

6. The apparatus of claim 1 wherein said at least one  
 module layer comprises an end cap, one feed screen as the  
 at least one first spacer layer and one membrane filter.

7. The apparatus of claim 1 wherein said at least one  
 module layer comprises an end cap, one filtrate screen as the  
 at least one first spacer layer and one membrane filter.

8. The apparatus of claim 1 including a second spacer  
 layer at each end of said membrane filter apparatus and said  
 at least one module layer comprising two membrane filters  
 separated by a filtrate screen as an at least one first spacer  
 layer.

9. The apparatus of claim 1 including a second spacer layer  
 at each end of said membrane filter apparatus and said at  
 least one module layer comprising two membrane filters  
 separated by a feed screen as an at least one first spacer layer.

10. The apparatus of claim 8 including an end cap  
 positioned on each second spacer layer at each end of said  
 membrane filter apparatus.

11. The apparatus of claim 9 including an end cap  
 positioned on each second spacer layer at each end of said  
 membrane filter apparatus.

12. The apparatus of claim 1 wherein one of said module  
 layers comprising a feed screen as a first spacer layer and a  
 membrane filter is positioned at each end of said membrane

filter apparatus and at least one of said module layers  
 comprises a feed screen positioned between two membrane  
 filters.

13. The apparatus of claim 1 wherein one of said module  
 layers comprising a filtrate screen as a first spacer layer and  
 a membrane filter is positioned at each end of said mem-  
 brane filter apparatus and at least one of said module layers  
 comprises a filtrate screen positioned between two mem-  
 brane filters.

14. The apparatus of claim 12 including an end cap at each  
 end of said membrane filter apparatus.

15. The apparatus of claim 13 including an end cap at each  
 end of said membrane filter apparatus.

16. The apparatus of claim 1 wherein one of said module  
 layers comprising a feed screen as a first spacer layer, an end  
 cap and a membrane filter is positioned at each end of said  
 membrane filter apparatus and at least one of said module  
 layers comprises a feed screen positioned between two  
 membrane filters.

17. The apparatus of claim 1 wherein one of said module  
 layers comprising a filtrate screen as a first spacer layer, an  
 end cap and a membrane filter is positioned at each end of  
 said membrane filter apparatus and at least one of said  
 module layers comprises a filtrate screen positioned between  
 two membrane filters.

18. The apparatus of claim 1 wherein said membrane  
 filters are microporous membranes.

19. The apparatus of claim 1 wherein said membrane  
 filters are ultrafiltration membranes.

20. The apparatus of claim 1 wherein said membrane  
 filters are nanofiltration membranes.

21. The apparatus of claim 1 wherein said membrane  
 filters are reverse osmosis membranes.

22. The apparatus of claim 1 which includes a plurality of  
 filtrate ports.

23. The apparatus of claim 1 which includes a plurality of  
 filtrate ports,

each of said module layers having two sets of filtrate tab  
 sections for a filtrate port,

said sets of tab sections being positioned on opposing  
 surfaces of each of said module layers so that said  
 filtrate tab sections on a first module layer are spaced  
 apart from filtrate tab sections on each module layer  
 adjacent said first module layer.

24. The apparatus of claim 1 which includes a plurality of  
 filtrate ports, each of said module layers having two sets of  
 feed tab sections for a filtrate port,

said sets of tab sections being positioned on opposing  
 surfaces of each of said module layers so that said  
 filtrate tab sections on a first module layer are spaced  
 apart from filtrate tab sections on each module layer  
 adjacent said first module layer.

25. The apparatus of claim 23 wherein said membrane  
 filters are microporous membranes.

26. The apparatus of claim 23 wherein said membrane  
 filters are ultrafiltration membranes.